

World Economic Forum

In collaboration with Accenture

Shaping the Future of Energy and Materials

System Value Framework – China Market Analysis

October 2020



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System Value of the clean energy transition in China

The System Value framework more holistically evaluates economic, environmental, social and technical outcomes of potential energy solutions across markets. The framework aims to **shift political and commercial focus beyond cost to include value**.

Using the System Value framework, the World Economic Forum, supported by Accenture, conducted analysis across several geographies as part of market evaluations that examined recovery opportunities to accelerate economic growth and the clean energy transition.

Key system value dimensions for China have been prioritized across the framework based on current market dynamics and its relative maturity of transition towards net-zero integrated energy system.



China recovery solutions

Solutions to deliver peak emissions before 2030

Utility-scale Wind and Solar

New utility-scale solar and wind capacity growth (incremental +282 GW wind, +173 GW solar by 2025) and **cost competitiveness** are boosted by falling levelized cost of energy (LCOE) of variable renewables alongside **government mandated renewable share target**.

Distributed Energy

Distributed energy is set to nearly triple over the next five years (incremental +138 GW distributed solar by 2025) as urbanization continues, costs fall, and subsidies support distributed and rooftop solar.

Internet of Energy

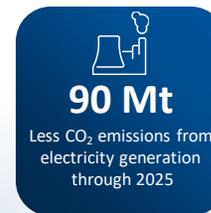
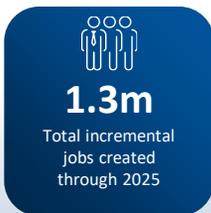
Continuous digital transformation of the power grid promotes **smart grid** developments and eventually the construction of a new digital energy ecosystem – **the Internet of Energy**.

Efficiency Investment

Efficiency opportunities across the value chain such as **grid, buildings, and industrial energy efficiency** can reduce load, driven by government energy saving policies.

Transport and Industrial Electrification

For transport, accelerate the construction of **charging infrastructure** and ongoing **electric vehicle (EV) purchasing subsidies**. For industry, continue to transform and **electrify manufacturing processes**.



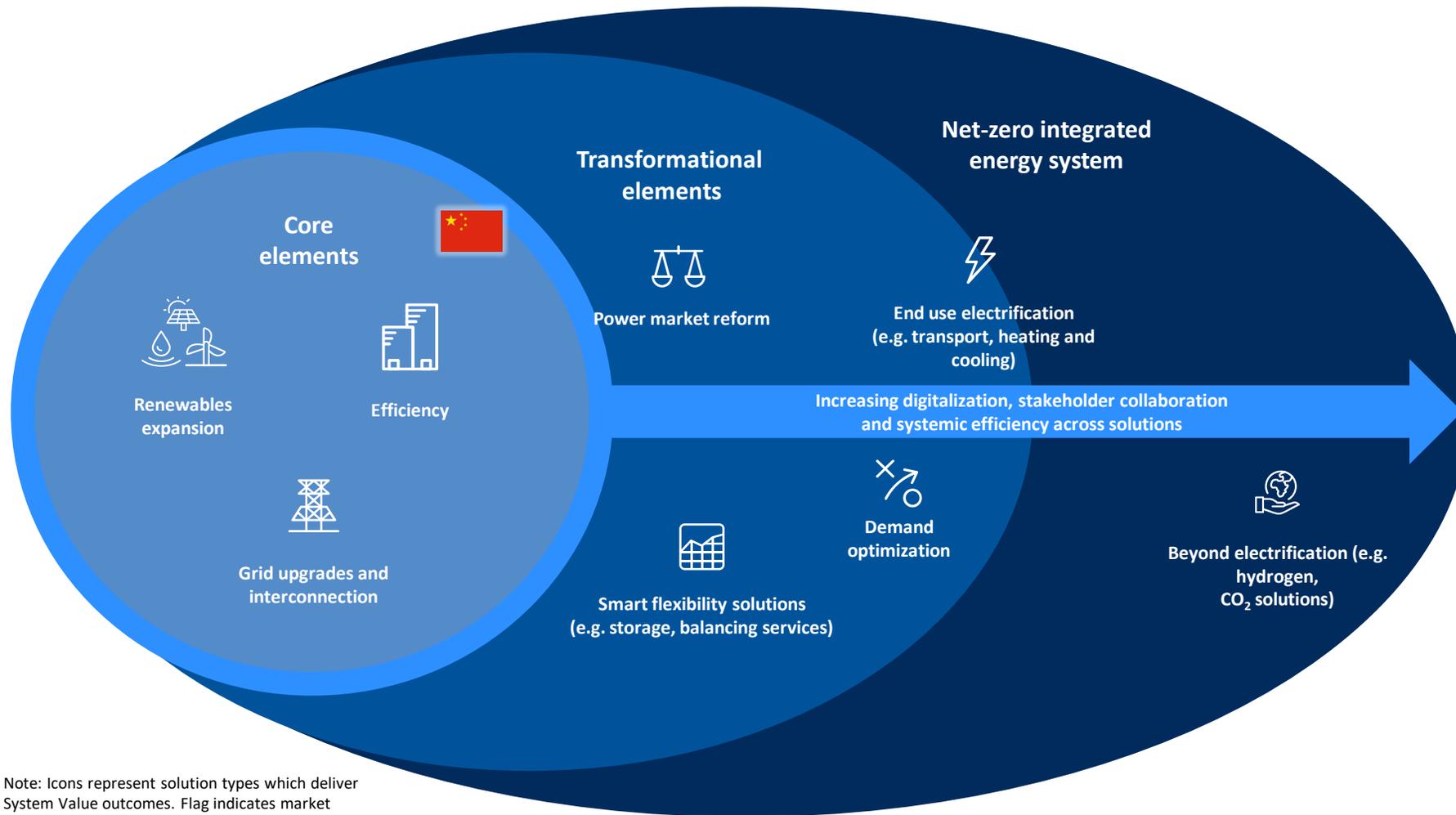
Note: Above CO₂ and human health benefit figures represent cumulative, incremental savings through 2025 compared to 2025 baseline.

China's path to maximize System Value

Markets are moving from addressing **core elements** of the electricity sector transition...

...through **"pivot points"** where generation mix hits 20-30% annual variable renewables (>50% instantaneous) and transformational elements enable...

... acceleration to a **net-zero integrated energy system** with a strong focus on systemic efficiency



China is nearing the pivot point.

Recovery solutions deliver against **core transition elements** and **push forward past the pivot point** towards an integrated energy system delivering net-zero GHG emissions.

To achieve **carbon neutrality by 2060**, the **14th Five-Year Plan** will need to **accelerate the pace** towards an integrated energy system.



Note: Icons represent solution types which deliver System Value outcomes. Flag indicates market progression along the path.

Analysis purpose and overview

The World Economic Forum, supported by Accenture, has developed the **System Value framework** to move beyond cost to a **more holistic evaluation** of energy sector opportunities across **economic, environmental, societal and energy system value dimensions**.



China's electricity market was one of several markets chosen to demonstrate how the System Value framework can be used to evaluate opportunities that **accelerate economic recovery and a clean energy transition**.

The following analysis of China's electricity market aims to answer several key questions for energy industry leaders and can be leveraged to consider opportunities to pursue and prepare for conversations with a range of stakeholders.

- What is the state of China's electricity market and initiatives impacting the energy transition for China?
- What short-to-medium-term growth opportunities exist that can spur economic recovery and accelerate the clean energy transition?
- How can stakeholders move beyond a cost-centric dialogue to consider the value of outcomes to the economy, environment, society and energy system?

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Energy transition trends shaping China's electricity industry



Energy security

- **Reducing import risk:** As a net energy importer, China is dependent on other countries for oil and natural gas. With geo-political relations becoming more strained, government policies have been moving to limit gas power development and support energy security goals. Barriers to the construction of new coal plants have been lowered.
- **High renewable investment:** During the 13th Five-Year Plan period, China's new investment in renewable energy is expected to reach \$360 billion, an increase of nearly 39% over the 12th Five-Year Plan period.



Domestic technology

- **Progress in solar PV technology:** China has an integrated value chain for its domestic solar PV industry, the world's largest, with the support of a robust research and development arm.
- **Technical patents:** China leads the world in the number of patents for renewable energy. As of 2016, the number of patents held was around 170k, 1.6 times that of the US and twice that of Japan.
- **Power system data:** According to the IEA, despite wide use of advanced digital technologies, the timeliness and availability of China's power data is not as advanced as Europe.



Lower total energy cost

- **Tariffs lowered:** Regulated gas-fired power tariffs have been lowered by 16-28% in key provincial markets since June 2020, partially driven by political goals of reducing end-user power prices. Power tariffs for industries in China have fallen 25% in the last three years.
- **Energy costs discounts:** A 5% discount on electricity prices was provided to many industrial customers from February to June, which contributed to revenue drops for both State Grid and China Southern.

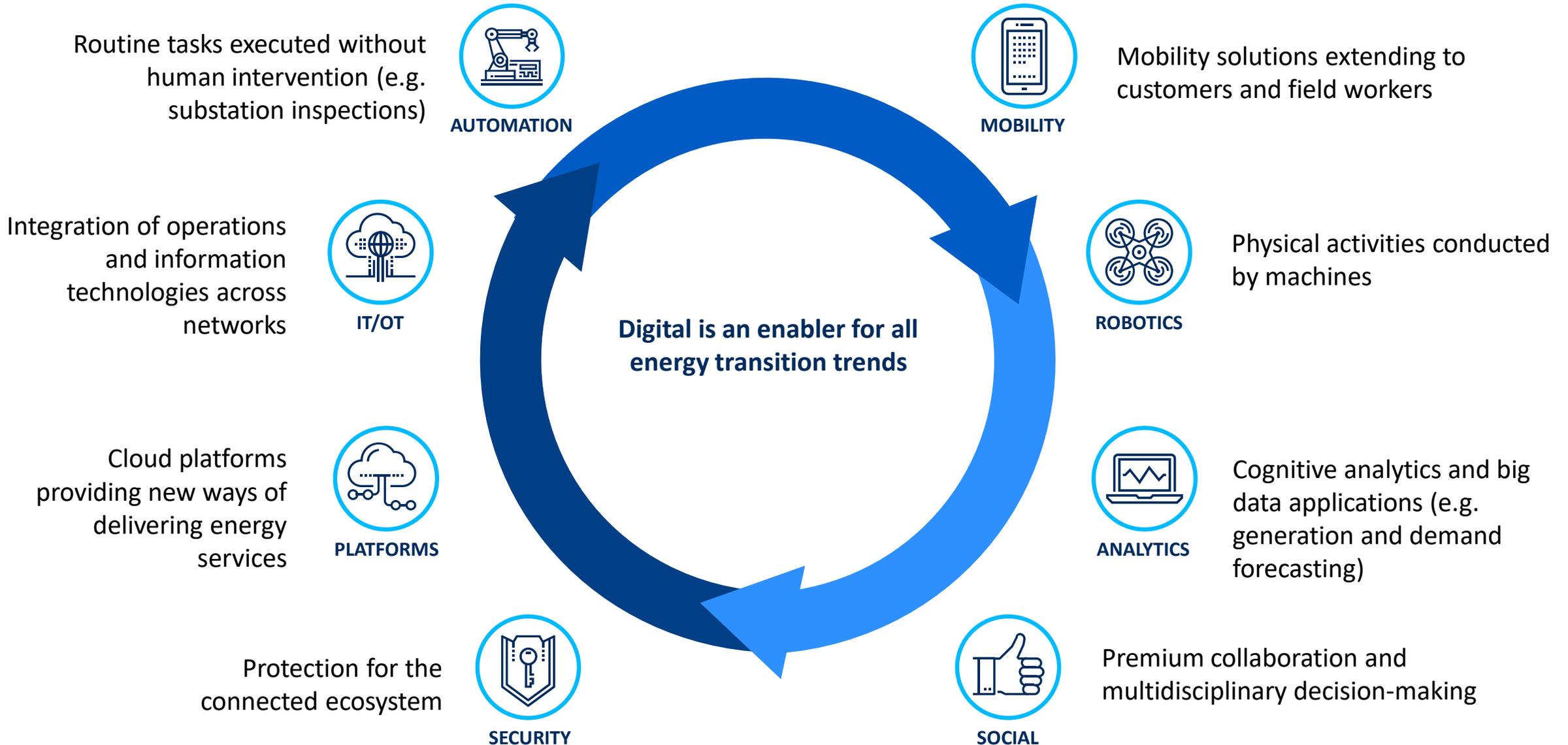


Climate change

- **Commitment to carbon peak and carbon neutrality:** In a September 2020 speech to the UN General Assembly, Chinese President Xi Jinping announced goal to peak its GHG emissions by 2030 and achieve carbon neutrality by 2060.
- **Low emissions steel industry:** In May 2018, the Ministry of Ecology and Environment of China proposed that qualified steel enterprises should comply with an ultra-low emissions plan and aim to complete the transformation of production capacity of 480 million tonnes of steel by the end of 2020.

Digital is an enabler for all energy transition trends

Digitalization underpins the energy transition



COVID-19 impacts to China's energy transition trends



Energy security

- **Price of oil drops:** COVID-19 has created a surplus in the global oil market and led to lower oil prices, which is helpful for China to achieve lower energy costs.
- **Energy demand:** Compared with the previous two years, the growth rate of China's total energy consumption in 2020 will further slow because of COVID-19. Meanwhile, the energy structure continues to improve.



Domestic technology

- **Solar PV supply chain:** A decline of China's exports of photovoltaic modules is inevitable due to the shortage of raw materials and challenges to logistics, transportation, and labor. However, the impact is expected to be short term.



Lower total energy cost

- **Slow construction and more cost:** Renewable energy projects delayed by COVID-19 may run the risk of not being able to obtain incentives from the Chinese government that will expire by the end of 2020. Furthermore, construction costs face increases as a result of restrictions on the number of workers allowed on site and strict hygiene regulation.



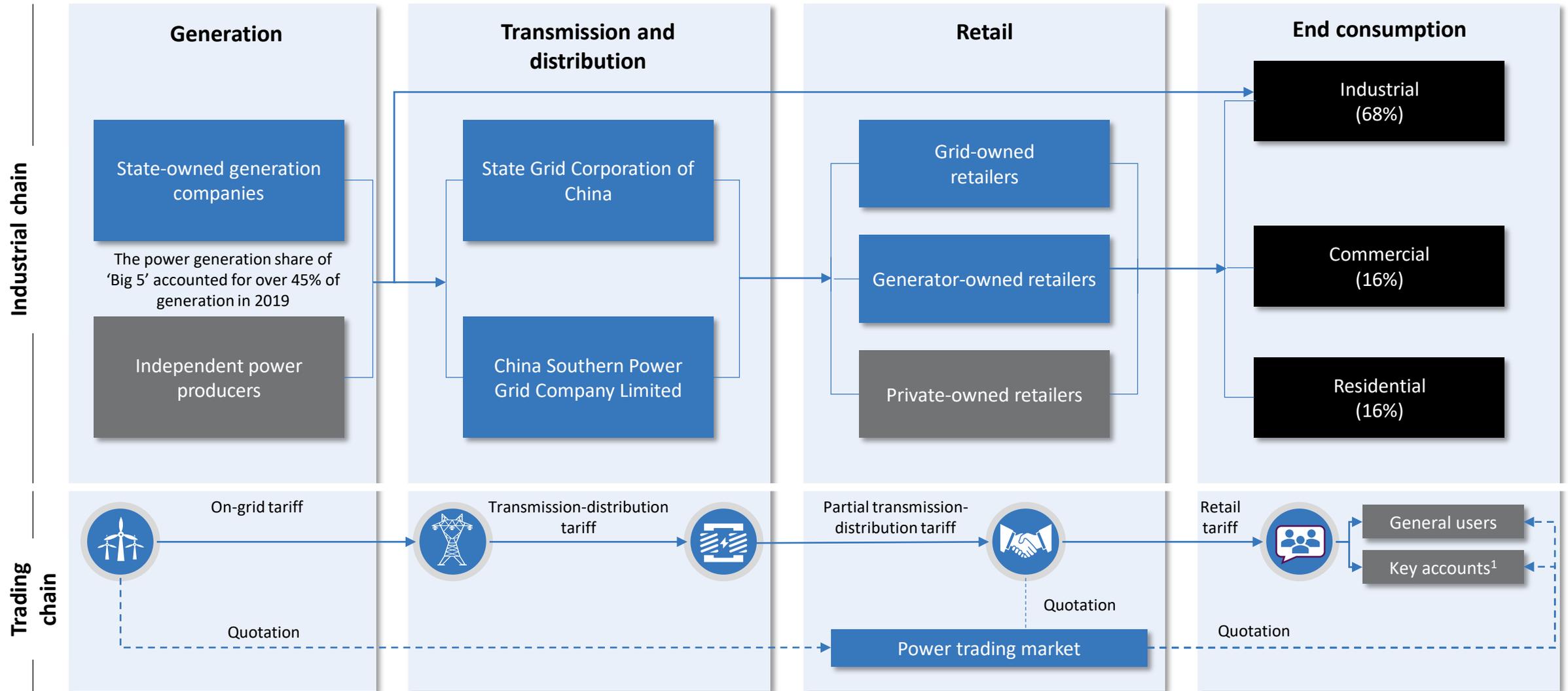
Climate change

- **Decrease in short-term emissions:** During the COVID-19 crisis, China temporarily saw a reduction in carbon emissions and local air pollution, with CO₂ emissions decreasing by 25% during Q1 2020.
- **Opportunity in LNG:** The epidemic has accelerated the overall easing of global gas supply, which provides an opportunity for China to achieve significant air quality gains without compromising industrial competitiveness.

Digital is an enabler for all energy transition trends

China's electricity market structure

Despite several rounds of reform over the past two decades, the vast majority of the power sector value chain in China is government-owned and operated.



¹ Currently key accounts but will be expanded to general users in the future
Source: Accenture analysis

China power market reform pilot areas

Since 2017, there have been eight designated power market pilot areas (Inner Mongolia, Fujian, Guangdong, Shandong, Zhejiang, Sichuan, Gansu and Shanxi), all of which have commenced with annual contracts and each moving at different speeds of reform.

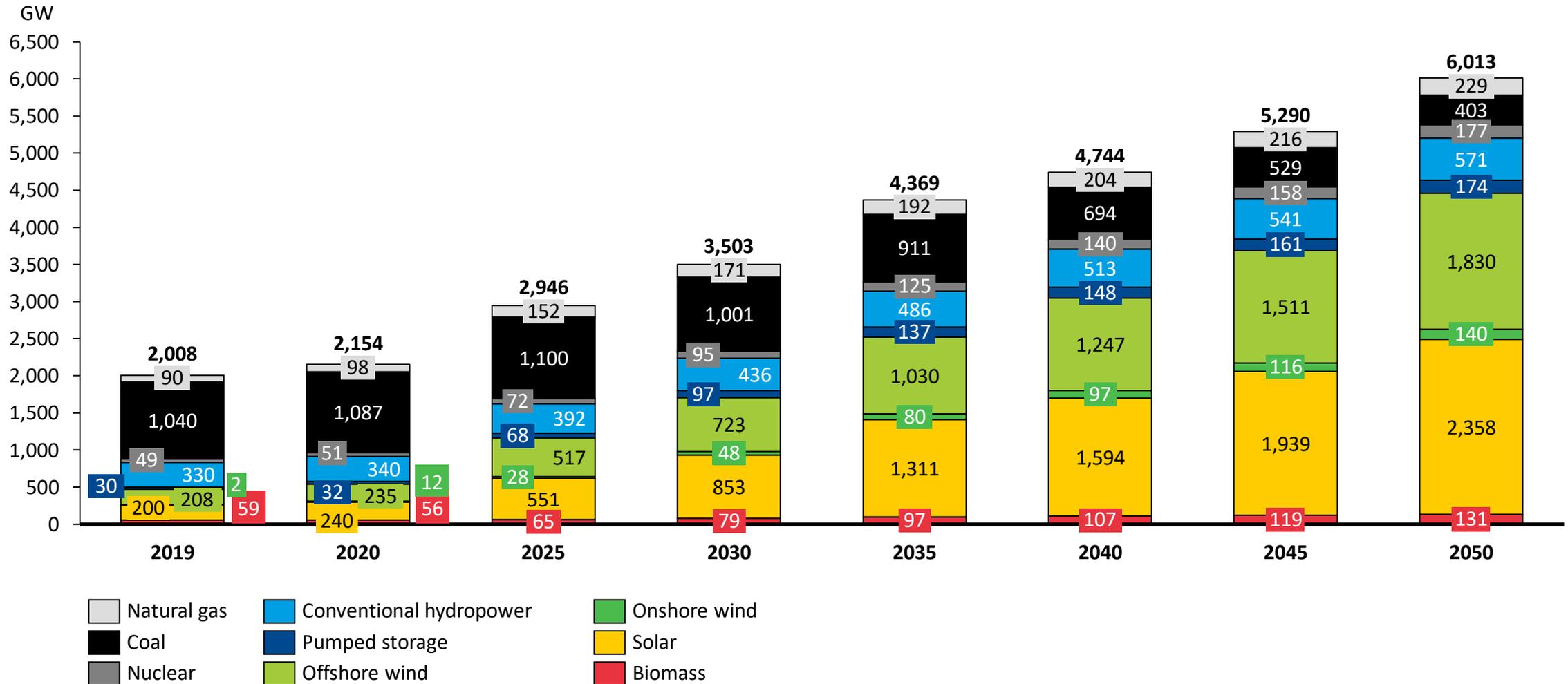
Example: Guangdong power market (~30% of the total electricity demand is traded in the market in 2019)

	Annual	Monthly	Spot (day-ahead)
Market dynamics	<ul style="list-style-type: none"> This is composed of a bilateral contract market between the generators and the customers (electricity users who have been granted access to the market) and a smaller annual contract auction market >80% of the total trading volume 	<ul style="list-style-type: none"> There is a 30% limit on the market share of retailers in the monthly market, though no limits on retailer market shares in the annual market ~ 15% of the total trading volume 	<ul style="list-style-type: none"> The spot market has yet to be switched on continuously, amid concerns that prices might both be volatile and ultimately rise above the current benchmark regulated industrial price at some nodes <5% of the total trading volume
Pricing mechanisms	<ul style="list-style-type: none"> The price is decided once per year and this covers most of the traded electricity 	<ul style="list-style-type: none"> The monthly market price has featured a market-determined discount on the regulated retail price The maximum discount is -500 basis points (1 point = 0.001Y per kWh) CSG* uses the market prices in the power market to discount both the price it charges to retail customers in the power market and the price it pays to generators in the power market CSG also pays the agreed margins to retailers in the power market 	<ul style="list-style-type: none"> Guangdong has made significant progress with technical implementation and trialing of its day-ahead market in some days of 2019 A software for implementing a day-ahead 15-minute power market calculates PJM type nodal prices at 2000 nodes The decision on running the spot market continuously is still pending as of August 2020

*Note: CSG = China Southern Power Grid
Source: [Guangdong Electric Power Trading Center](#)

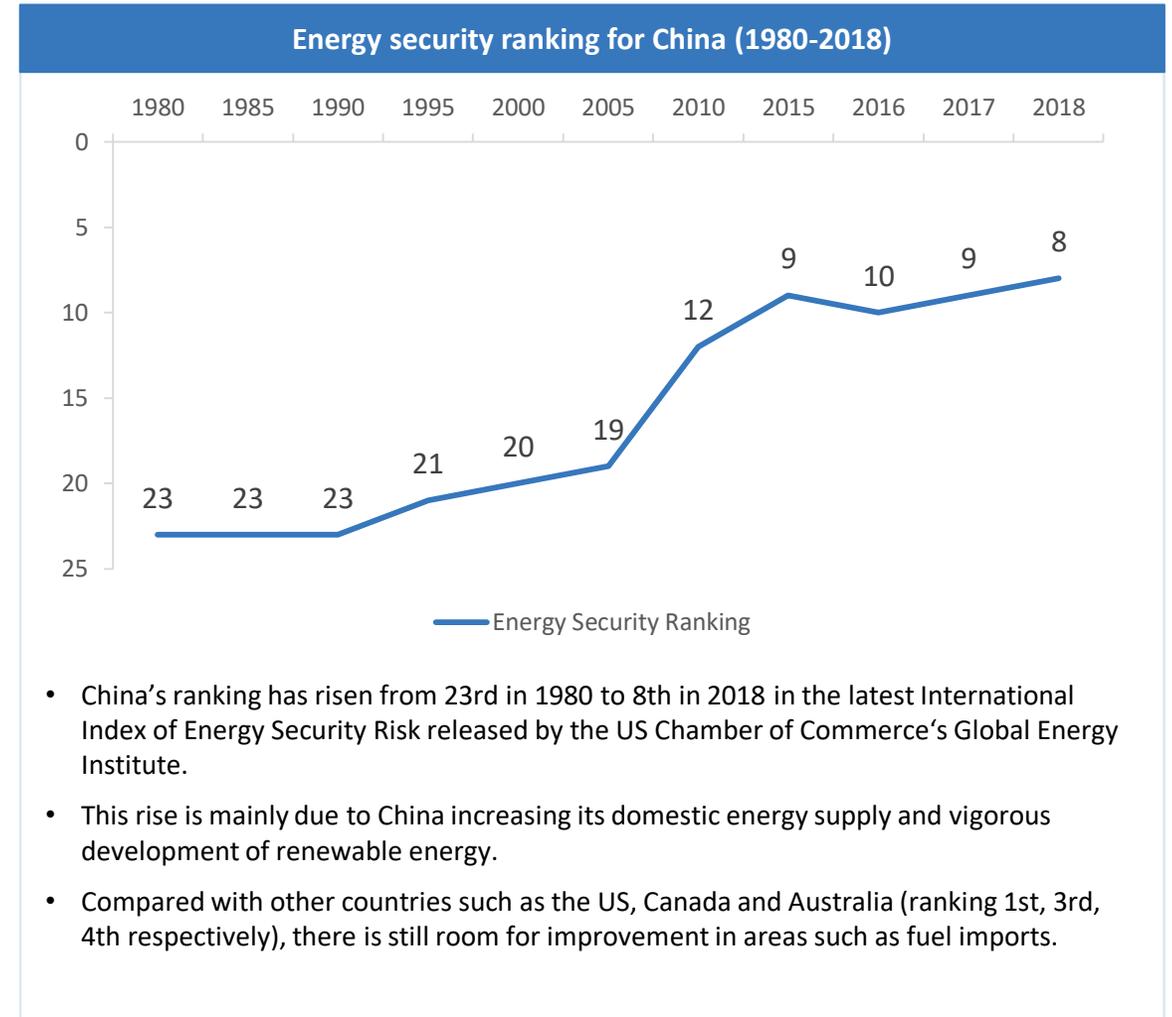
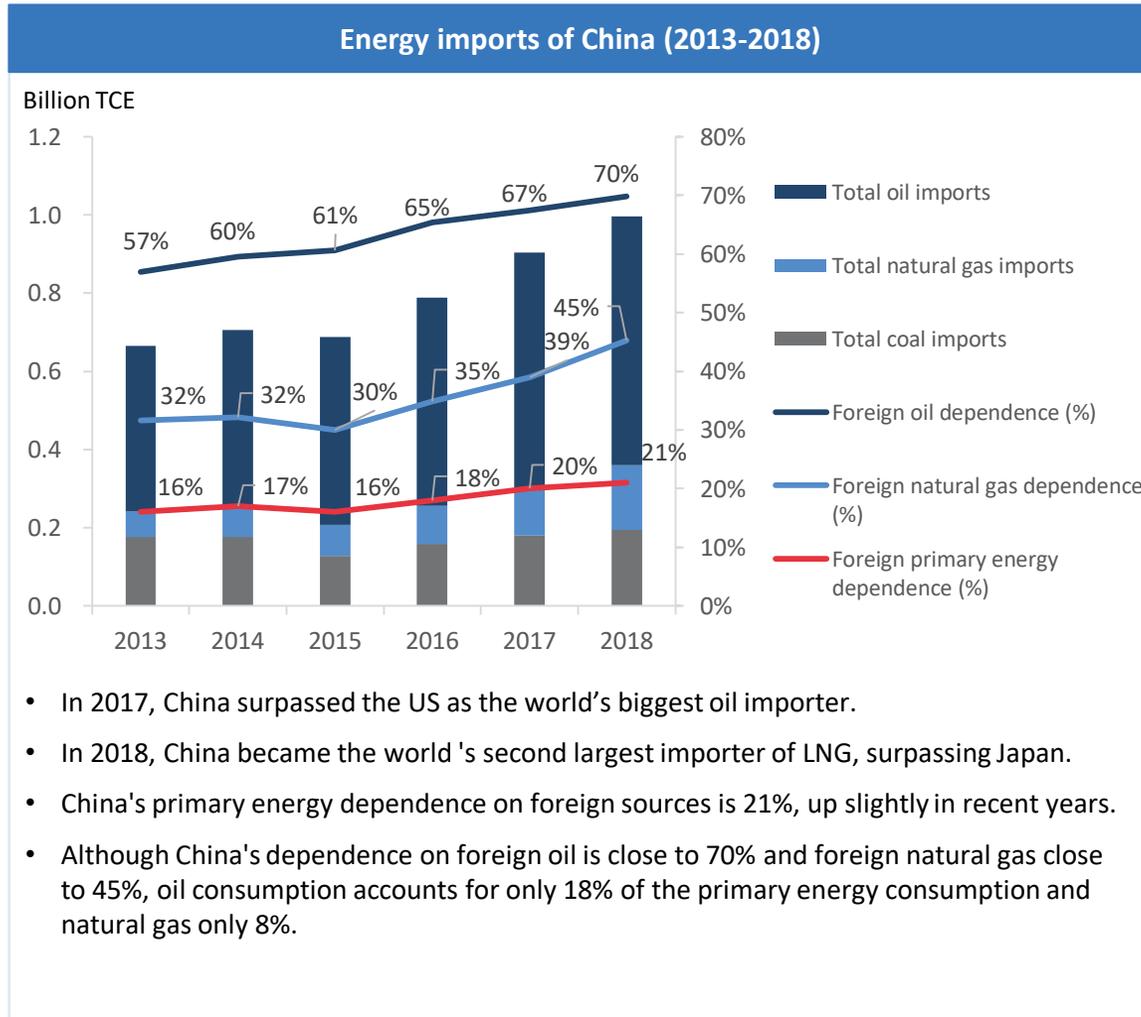
China power capacity structure

China's coal capacity is expected to drop 63% from 2019 to 2050 (1,040 GW to 403 GW), with renewable energy capacity share rapidly growing from 41% to 87%, paving the way for clean energy to be the leading energy source.



China's energy security

China's global energy security ranking has improved in recent years, though its foreign dependence on primary energy has been rising slightly (16% in 2013 to 21% in 2018).

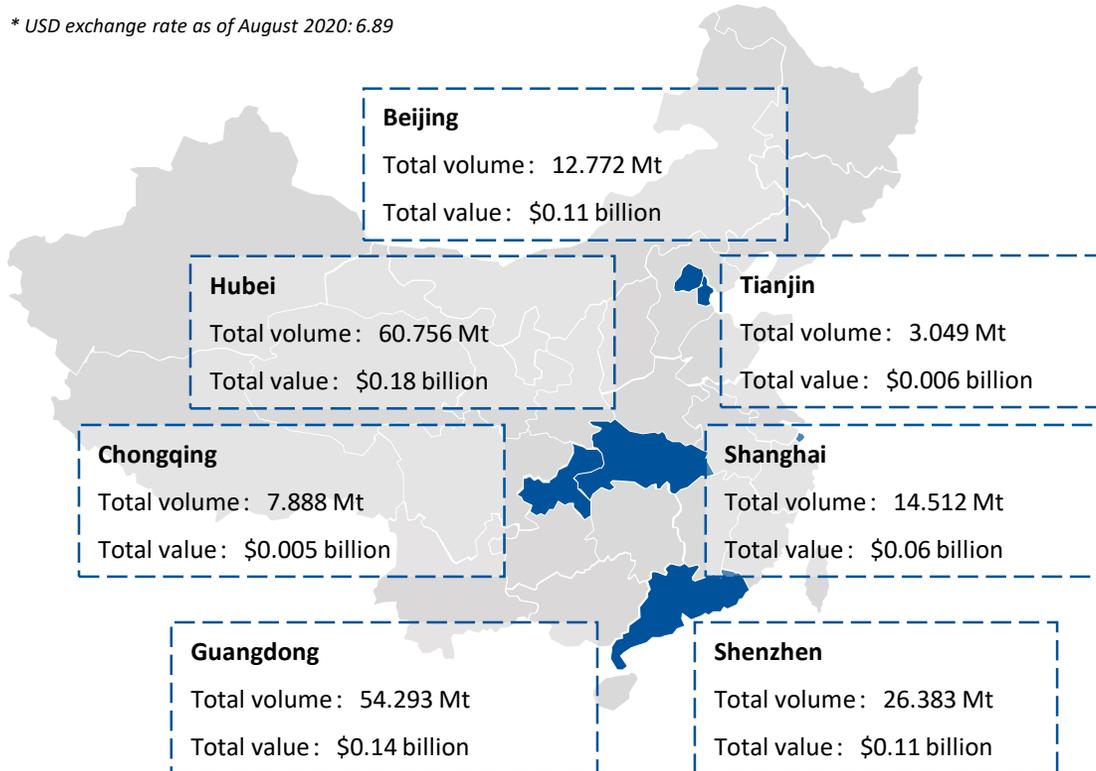


China's carbon market

China introduced a carbon emissions pilot in 2012 across 2 provinces and 5 cities; however, persistently low carbon prices and the distribution of free quotas hinder progress on decarbonization.

Low carbon price seen across all 7 pilot markets in China (2012-19)

* USD exchange rate as of August 2020: 6.89



- 2019 carbon price per ton: Beijing \$8.68, Shanghai \$4.03, Shenzhen \$3.99, Hubei \$2.89, Guangdong \$2.55, Tianjin \$2.00, Chongqing \$0.60
- **The prices are relatively low, ranging from \$0.60 to \$8.70 USD per tonne**

Free quotas dominate the market

\$'000 USD

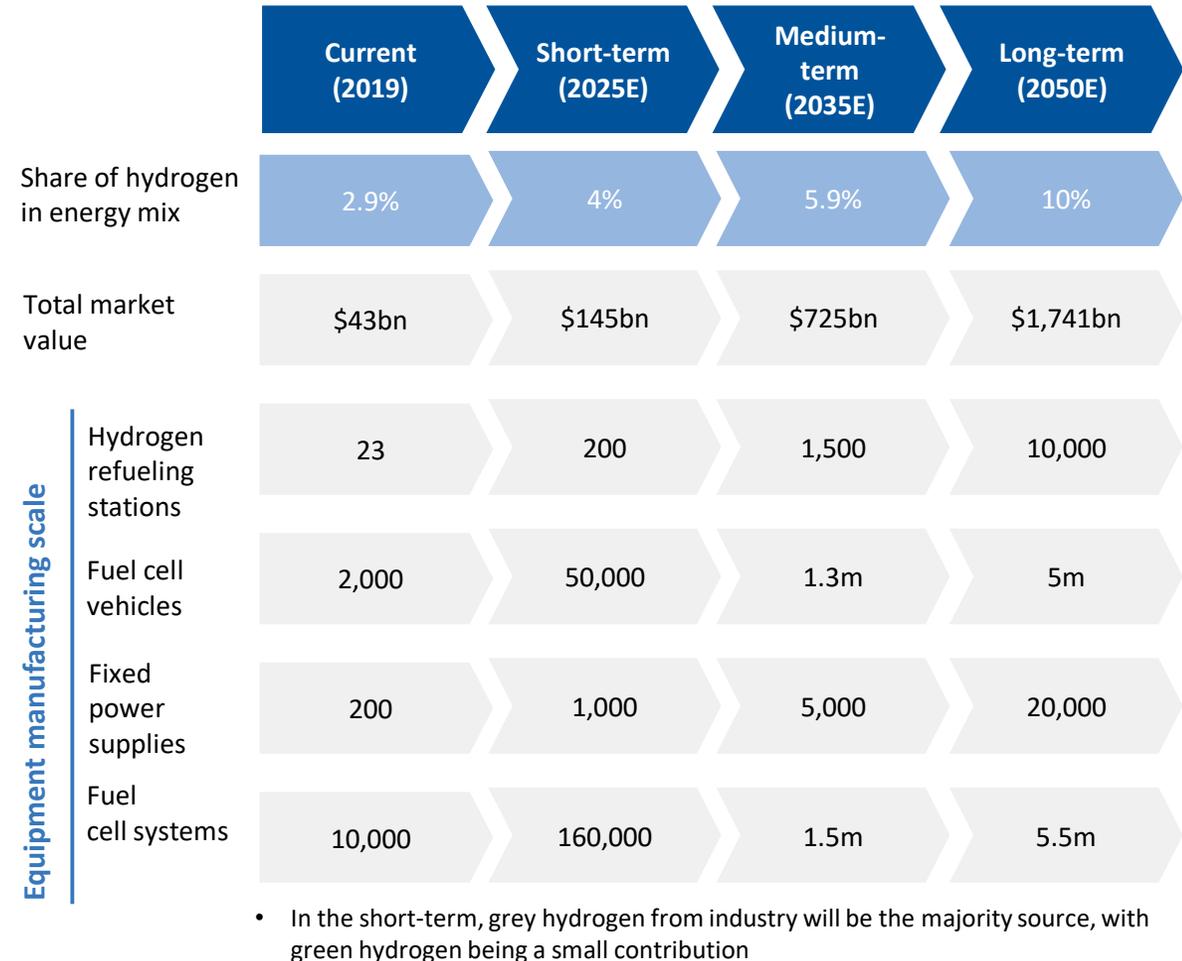
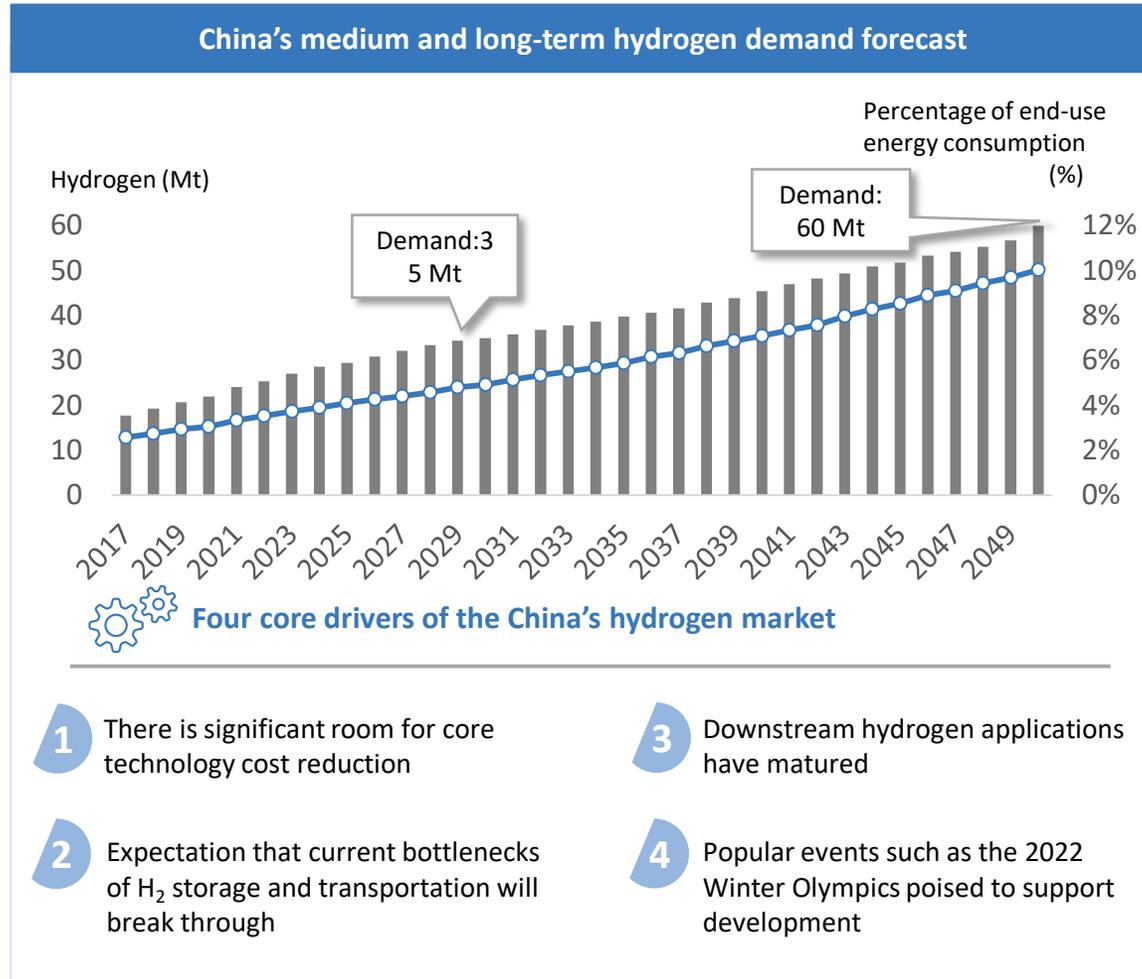


- Although China's various carbon pilot markets have been in operation for many years, free quota trading dominates the trading market and the actual auction volume is relatively small.
- The national-level carbon market and the carbon financial market is developing slowly.

* USD exchange rate as of August 2020: 6.89

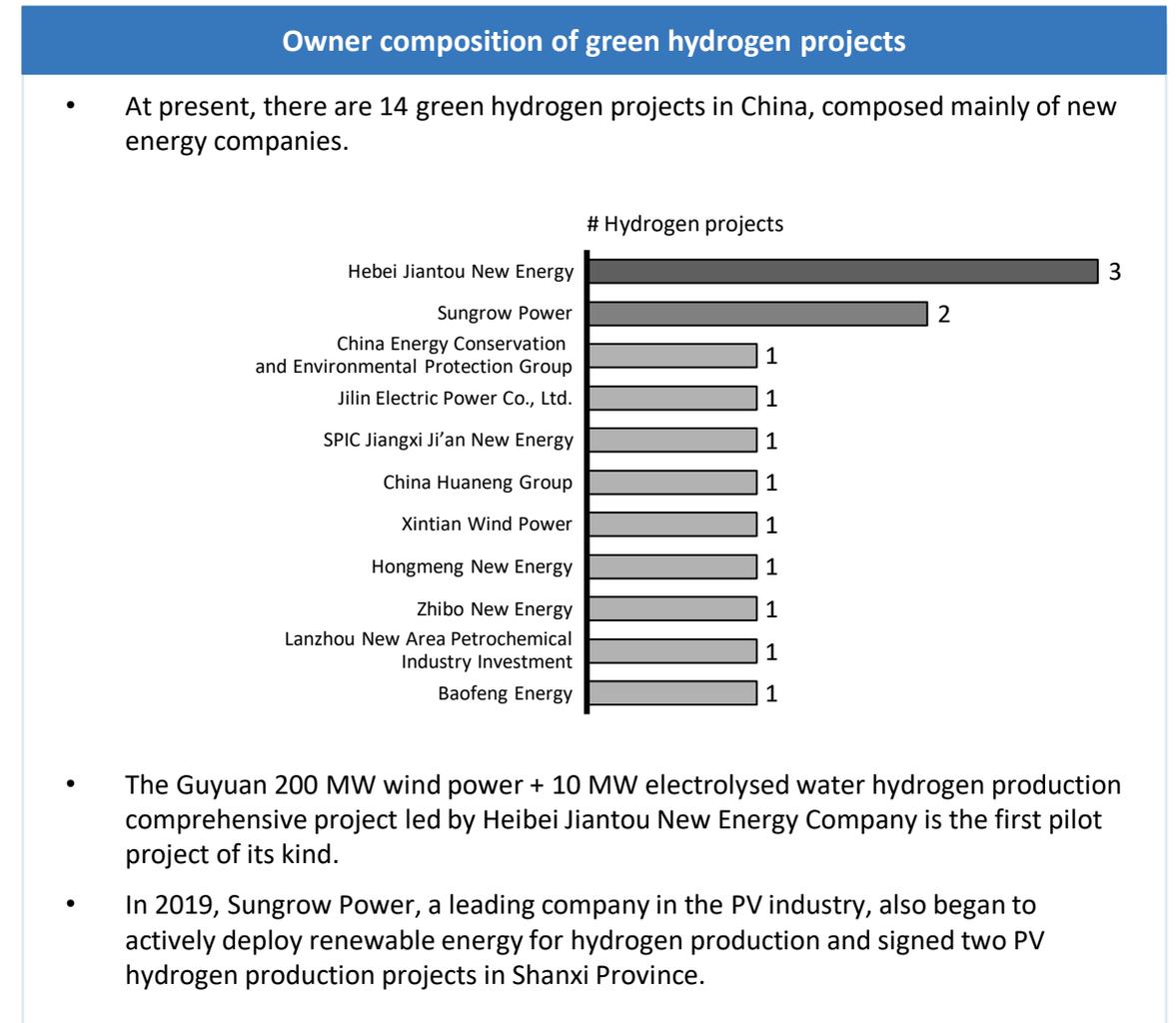
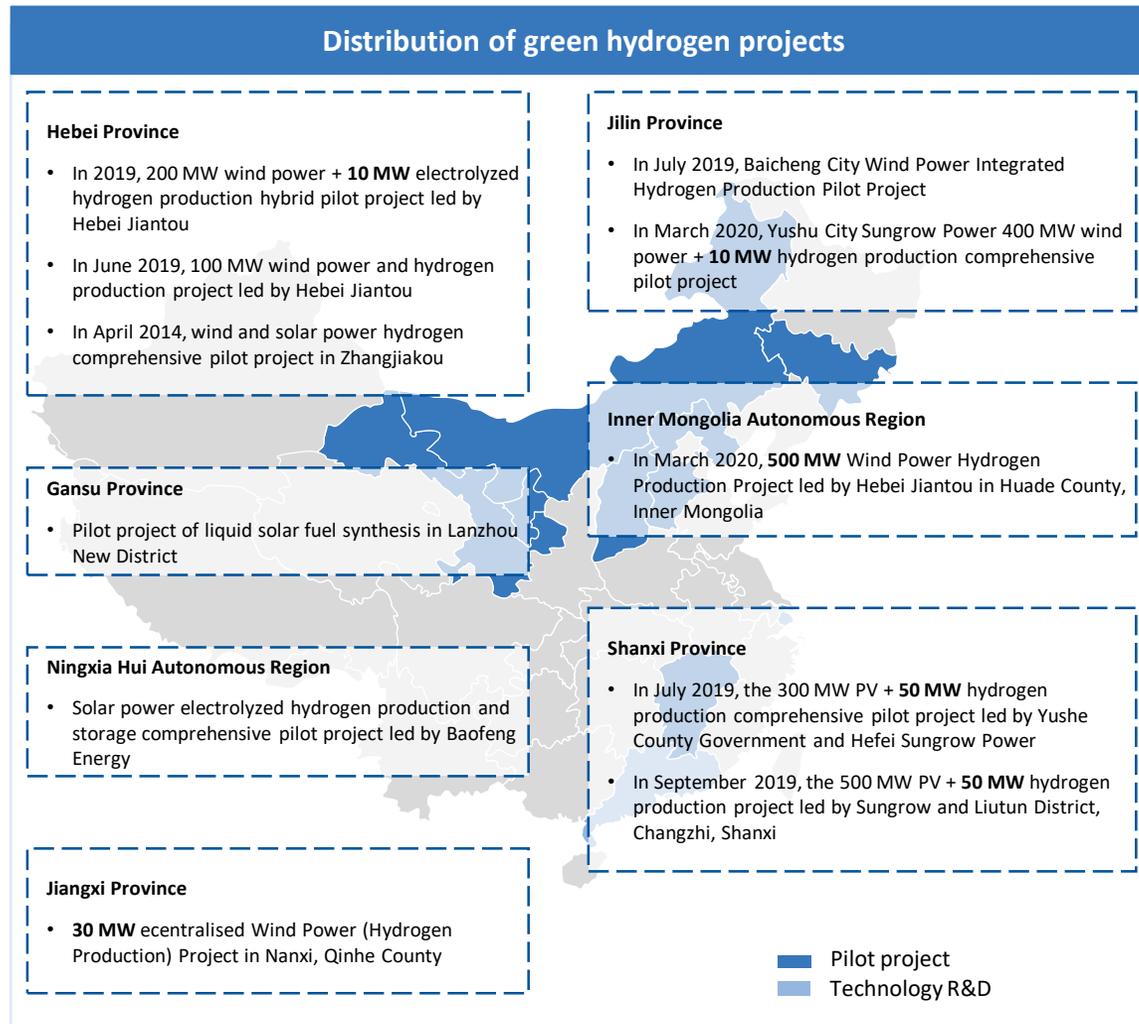
China's hydrogen market

The market value of the hydrogen industry is expected to grow significantly in coming decades, with opportunities emerging across hydrogen value chain.



China's green hydrogen market

Green hydrogen production is still in the early stages in China and key investment entities are relatively scattered, mostly made up of leading renewable energy companies.



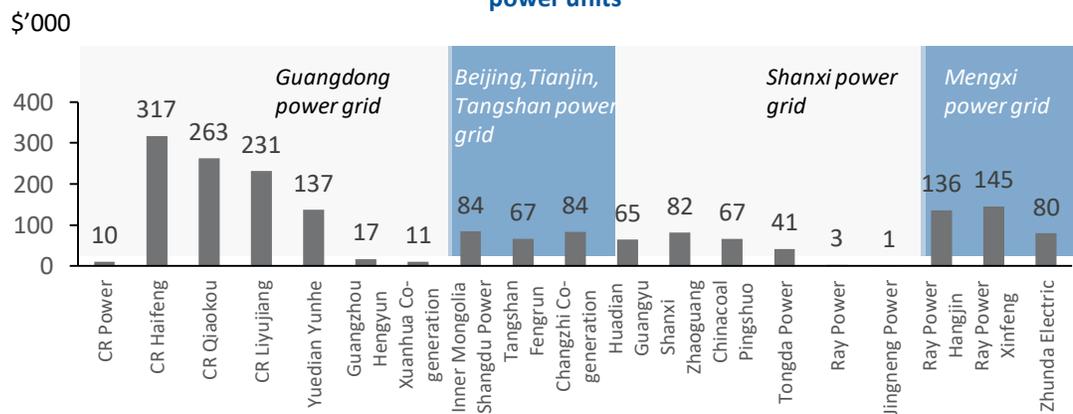
Thermal power with energy storage participating in the ancillary services market

China has a coal-based power generation system that has minimized the need for formal ancillary services markets, and thus lacks a formal payment mechanism for ancillary services.

Economic benefits of thermal power and energy storage

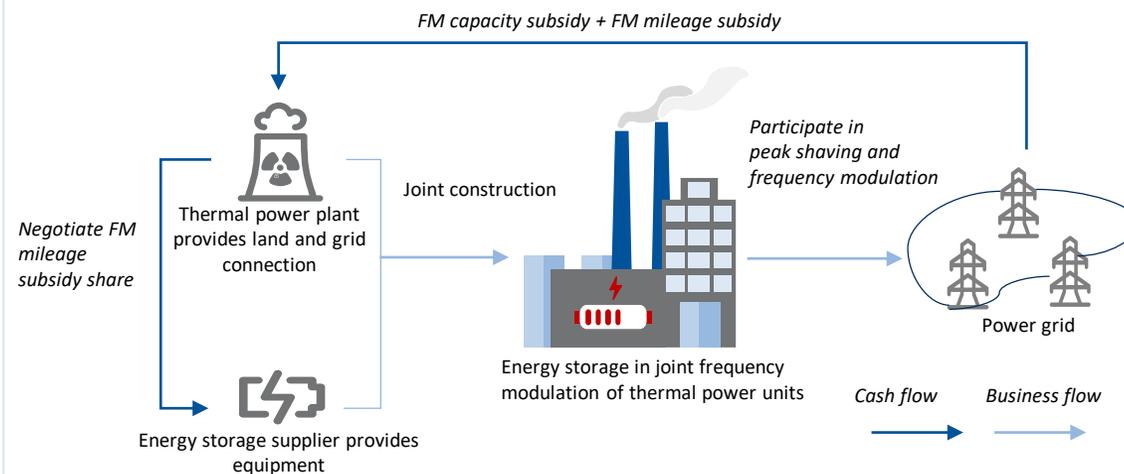
- An increasing number of provinces and cities have introduced subsidy policies for ancillary services, and the number of market participants for energy storage in joint frequency modulation of thermal power units continues to increase.

Average monthly income of energy storage in joint frequency modulation of thermal power units



- The monthly income of thermal power storage varies across locations and individual plants, with Guangzhou and Mengxi leading.
- The 'big five' and big local power generation companies are key energy storage participants in the joint frequency modulation of thermal power units.

Thermal power and energy storage in joint frequency modulation business model



- Energy storage within the joint frequency modulation of thermal power units is generally funded through energy storage investment companies, while thermal power plants provide land and grid connection.
- Once a thermal power plant has built energy storage equipment, it will jointly participate in peak shaving and frequency modulation in the power ancillary market.
- The current ancillary service charges and grid tariffs use the “daily calculation and monthly calculation” model, which is settled by the grid to the plant and finally to the energy storage investment company; however, the actual settlement cycle ranges from 6-12 months, which may form “chain debts”.

The market for renewables + storage, behind the meter storage

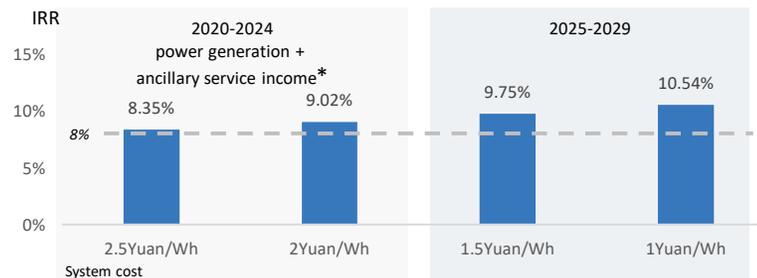
Storage system deployment, including utility-scale, behind-the-meter and renewables-plus-storage, are poised to rapidly develop in the coming years as the cost of storage systems is expected to further decline.

Priority RE + storage projects are growing across provinces

- Five provinces in China have made clear requirements for the installed capacity of energy storage systems, energy storage duration and other factors.
- Some provinces have clearly defined the types of renewable energy storage projects to be supported as a priority.

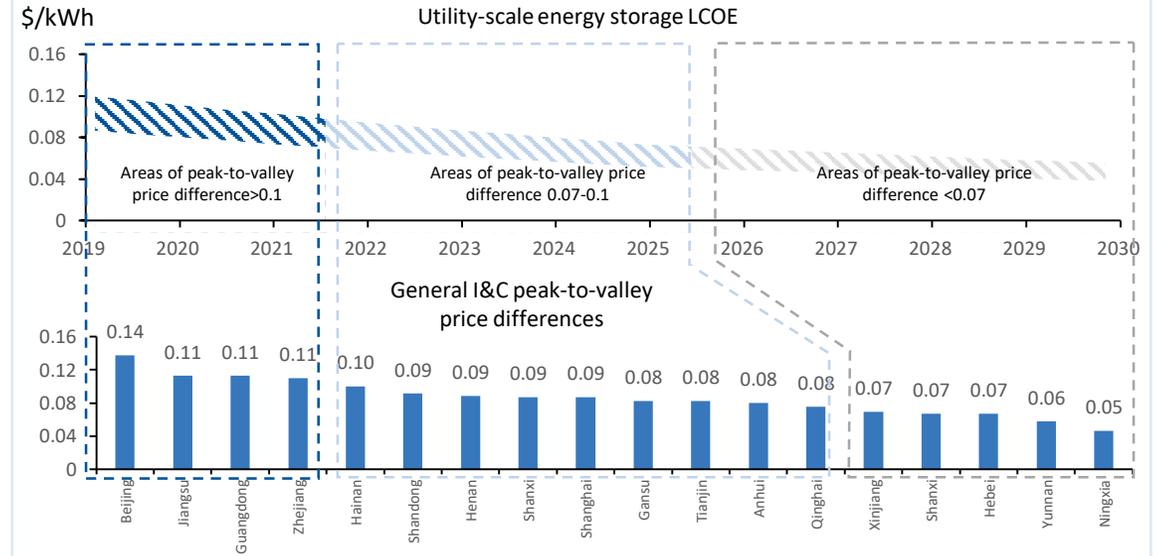
Province	Energy storage capacity requirements	Main content
Xinjiang	15%, 2h	Energy storage power station needs to be equipped with 15% of PV installed capacity
	>10MW/20MWh	Compensate 0.08 USD/kWh according to charging power
Inner Mongolia	5%, 1h	Priority support for solar storage projects, with a capacity of no less than 5%, and an energy storage period of more than one hour
Shanxi	15-20%	New PV projects need to be equipped with 15-20% energy storage
Shandong	20%, 2h	Energy storage system is considered based on 20% of installed capacity, and energy storage time is two hours
Hubei	10%	Energy storage system is equipped based on 10% of installed capacity

Centralized photovoltaic + energy storage has achieved economic profitability



- New energy + energy storage, which reduces power curtailment and obtains ancillary service income, has achieved an 8% yield in 2020.
- As the cost of energy storage systems decreases, IRR can reach 10.54% in 2025-2029.

Economic benefits emerge through peak-to-valley price differences



* USD exchange rate as of August 2020: 6.89

2020-2021

- Target cities:** Beijing, Jiangsu, Guangdong, Zhejiang
- Reason:** The peak-to-valley price difference is greater than 0.1 USD/kWh, which is economical for development

2022-2025

- Target cities:** Hainan, Shandong, Henan, Shanxi, Shanghai, Gansu, Tianjin, Anhui, Qinghai
- Reason:** The peak-to-valley price difference is 0.07-0.1 USD/kWh, which is expected to be economical for development in 2022

2026-2030

- Target cities:** Xinjiang, Shanxi, Hebei, Yunnan, Ningxia
- Reason:** The peak-to-valley price difference is less than 0.07 USD/kWh, which is expected to be economical for development in 2026

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Recovery solution selection criteria

Selected recovery solutions are required to meet the following criteria:

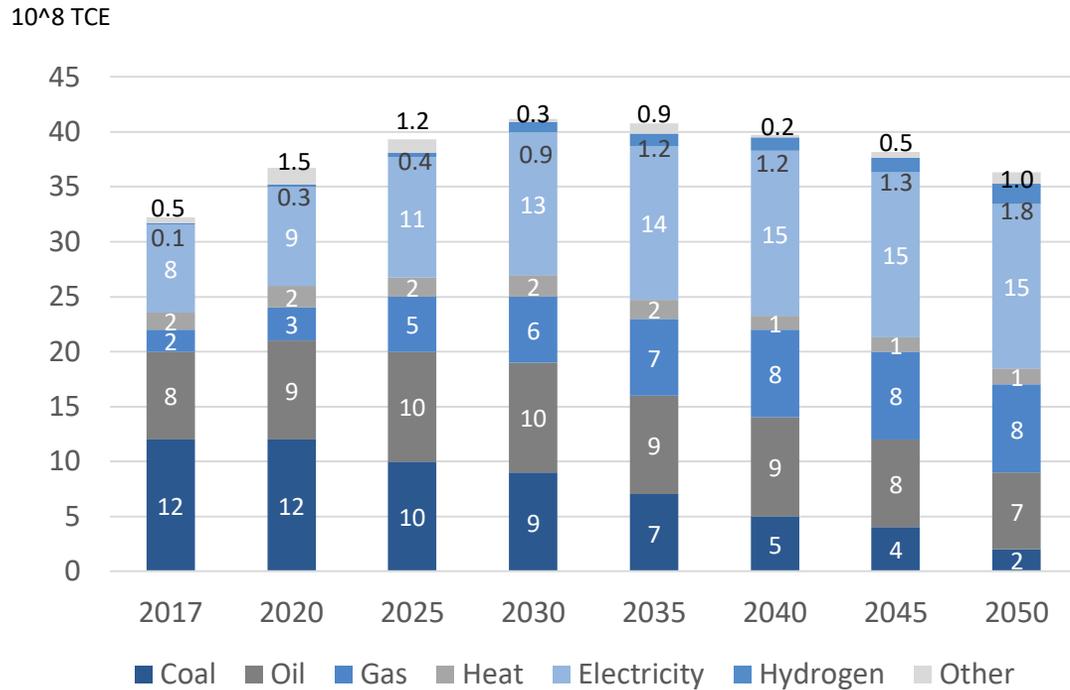
- 1 Accelerates the energy transition**
The recovery solution moves the market closer to net zero



- 2 Stimulates economic recovery**
Implementation of the recovery solution should stimulate job creation by 2021+
- 3 Enables meaningful System Value assessment**
It should be possible to model and assess the recovery solution for meaningful results within a 2025 time horizon

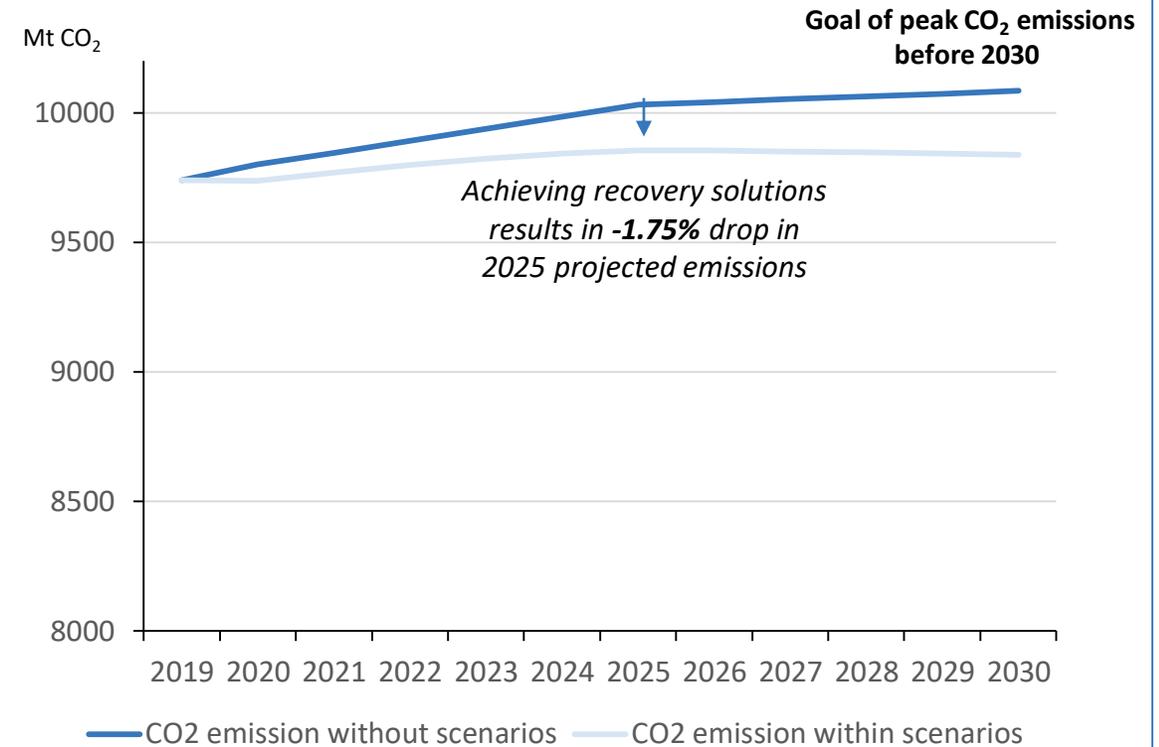
China baseline energy consumptions and emissions forecast

End-use energy consumption of China from 2017 to 2050



- **Non-fossil fuels** will have a faster **growth curve**, accounting for 36% and 53% of the primary energy consumption by 2025 and 2030, respectively.
- The proportion of **coal** will steadily **decline**, dropping from 37% in 2017 to 6% in 2050.
- The proportion of **gas** will continue to **rise**, reaching from 6% in 2017 to 22% in 2050.

Expected CO₂ emissions in China from 2019 to 2030



- In September 2020, China announced intent to peak carbon emissions by 2030, en route to carbon neutrality before 2060.
- CO₂ emissions can be reduced **665** million tonnes cumulatively from 2020-2025 through five recovery solutions.

Base case emissions from Energy Outlook 2050 (CNPC ETRI 2019)

Recovery solutions can support China post-COVID and advance the clean energy transition

	Utility-Scale Wind and Solar	Distributed Energy	Internet of Energy	Efficiency Investment	Electrification	
					Transport Electrification	Industrial Electrification
Solution overview	New solar and wind capacity growth and cost competitiveness are boosted by falling LCOE of variable renewables combined with government mandated renewable share target.	Distributed energy is set to nearly triple over the next five years as urbanization continues, costs fall, and subsidies support distributed and rooftop solar.	Continuous digital transformation of the power grid promotes smart grid developments and eventually the construction of a new digital energy ecosystem – the Internet of Energy.	Efficiency opportunities across the value chain such as grid, building and industrial energy efficiency can reduce load, driven by government energy saving policies.	Accelerating construction of charging infrastructure and ongoing EV purchasing subsidies will stimulate electrification of transport in China.	Electrification set to play a large role in controlling total coal consumption and reducing air pollution in the industrial sector.
Capacity and generation impact	<ul style="list-style-type: none"> +104% (339 GW) utility-scale solar capacity by 2025, 12% of installed capacity +120% (517 GW) utility-scale wind capacity by 2025, 18% of installed capacity 35 x 500MW coal plants avoided in total 	<ul style="list-style-type: none"> +188% (212 GW) distributed solar cumulatively in 2025, 7% of installed capacity +133% (28 GW) distributed wind cumulatively in 2025, 1% of installed capacity 27 x 500MW coal plants avoided in total 	<ul style="list-style-type: none"> 1.6% of total energy demand (144 TWh) saved by reducing system losses cumulatively through 2025 Losses improved from 5.9% to 5.48% 	<ul style="list-style-type: none"> 1% of total energy demand (97 TWh) saved of Target Year Efficiency Benefit (in 2025) 	<ul style="list-style-type: none"> For incremental EV energy consumption, 176 TWh of renewable energy generation replaces fossil fuels cumulatively from 2020 to 2025 	<ul style="list-style-type: none"> 347 TWh renewable energy generation used for replacing fossil fuels energy of industrial end-use energy consumption cumulatively from 2020 to 2025
CO ₂ emissions	↓ 276 Mt Cumulative reduction through 2025	↓ 82 Mt Cumulative reduction through 2025	↓ 56 Mt Cumulative reduction through 2025	↓ 90 Mt Cumulative reduction through 2025	↓ 60 Mt Cumulative reduction through 2025	↓ 100 Mt Cumulative reduction through 2025
Water footprint	↓ 561bn litres Cumulative reduction through 2025	↓ 137bn litres Cumulative reduction through 2025	↓ 115bn litres Cumulative reduction through 2025	↓ 184bn litres Cumulative reduction through 2025	↓ 84bn litres Cumulative reduction through 2025	↓ 112bn litres Cumulative reduction through 2025
Jobs Impact	↑ 1.35m Total incremental jobs created from 2020-2025	↑ 1m Total incremental jobs created from 2020-2025	Not included in analysis	Not included in analysis	↑ 0.63m Total incremental jobs created from 2020-2025	↑ 1.17m Total incremental jobs created from 2020-2025
Air quality and health	↑ \$14.1bn Human health benefits from air quality improvements through 2025	↑ \$4.2bn Human health benefits from air quality improvements through 2025	↑ \$2.8bn Human health benefits from air quality improvements through 2025	↑ \$4.6bn Human health benefits from air quality improvements through 2025	↑ \$2.7bn Human health benefits from air quality improvements through 2025	↑ \$5.5bn Human health benefits from air quality improvements through 2025

Mt = million (metric) tonnes.

Utility-scale Wind and Solar

Overview

Wind power:

- Wind power has become China's third largest power source after hydropower and coal power. By the end of 2020, grid-connected installed wind capacity and annual generation is expected to reach 235 GW and 420 TWh, respectively, accounting for 6% of the country's total power generation.
- In terms of geographic placement, new offshore wind installations are expected to be concentrated in the southeast, with onshore wind concentrated in north-western districts of China.

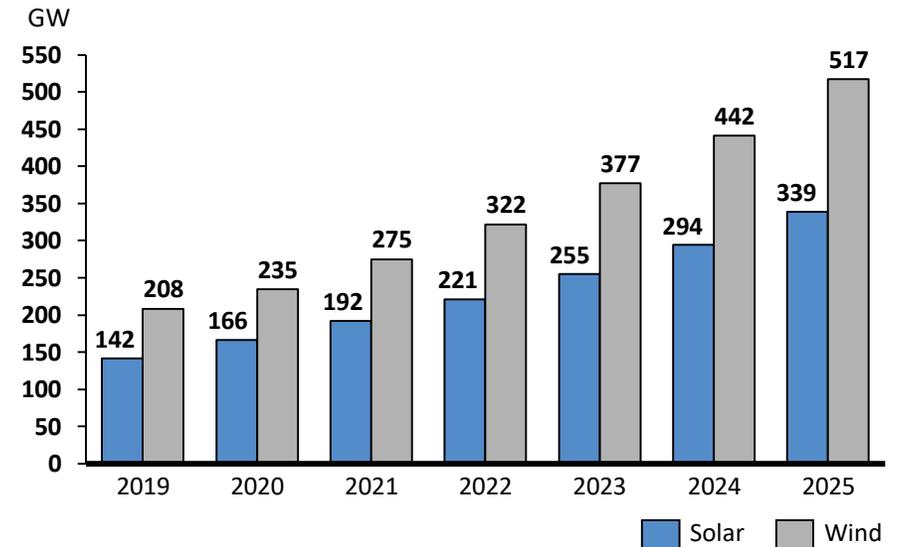
Solar power:

- The rapid growth of China's solar energy industry began in 2004. A comprehensive solar energy industry policy system was gradually established, including a multi-level policy framework incorporating pricing, subsidies, taxes, and grid connection. Industry standards and testing and certification systems were also developed.
- In terms of scale, China's cumulative installed capacity was 200 GW in 2017 and is expected to reach 551 GW by 2025. The price of PV power generation is expected to drop by over 50% in 2025 compared to 2015 prices, and following a reduction in transmission and distribution tariffs, low-cost grid access can act as an additional enabler.

Policy and enforcement

- Contradictions continue to exist in the energy space that impact renewable deployment, e.g. national guidance versus local implementation, support for coal co-existing with promotion of renewables, and the slow rollout of spot electricity markets.
- Nonetheless, China's energy market constitutes a hybrid of market and policy measures which could favour a clean energy transition according to a recent study by Oxford University.
- Under the 12th Five-Year Plan and the 13th Five-Year Plan, the National Energy Administration (NEA) sets ambitious targets for wind and solar, supported by subsidized feed-in tariffs to support steady growth. In parallel, however, the NEA has green-lighted many provinces to invest in coal generation since 2016 for system reliability reasons.
- The current government plan calls for "stable growth" of renewable energy, and the policies released thus far in 2020 support this intention.

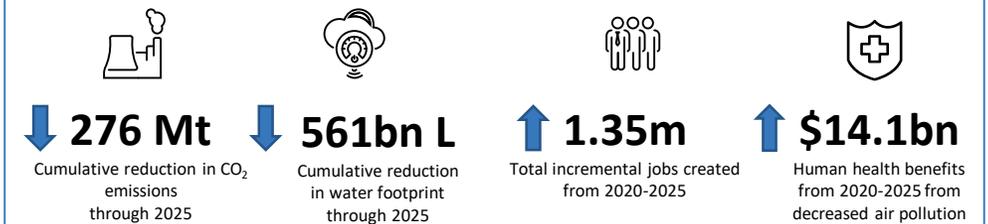
Projected utility-scale wind and solar installed capacity



Source: GEIDCO

System Value impacts

Benefits



Distributed Energy

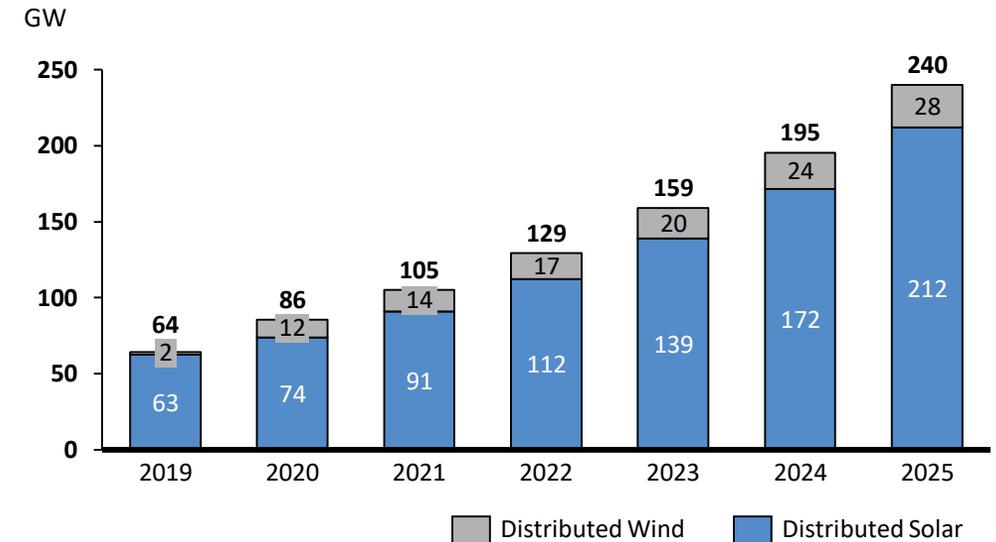
Overview

- Decentralized, flexible, clean and efficient distributed energy will become an indispensable part of China's energy supply.
- China is in a critical period of economic structural transformation, with the proportion of heavy industry declining and the proportion of commerce and service industries rising. Thus the proportion of distributed loads (commercial and small industrial facilities) is expected to increase, with energy demand becoming more dispersed and flexible.
- It is anticipated that a turning point in the development of distributed energy is coming, given the following three reasons:
 - The cost of distributed energy power generation has dropped significantly, and scaled benefits can be expected
 - The policy of special subsidies is currently focused on subsidizing distributed and rooftop solar
 - M&A activities involving distributed energy assets continue to gain traction

Policy and enforcement timeline

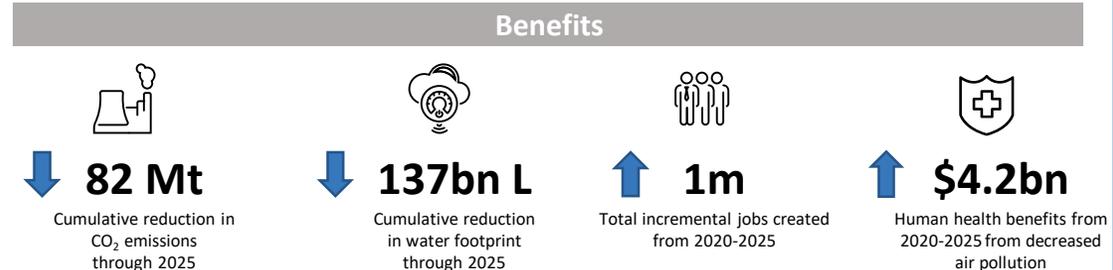
- 2015/2016: Promoted the coordinated development of distributed renewable energy and natural gas distributed energy and improved the level of comprehensive utilization. Accelerated DER sector reform, opening up the construction of distributed power sources on the user side.
- 2017: Confirmation of no scale limitations for DER capacity installations. Set distributed natural gas as the main method of natural gas utilization and direct trading as the distributed power generation mode.
- 2018/2019/2020: Promoted the marketisation of distributed PV resource allocation and carried out pilot projects for distributed power trading between power users and grid companies. The first batch of pilot distributed market trading areas was officially launched in May 2019 across 26 cities.
- 2020: Given the cost competitiveness of utility-scale solar and on-shore wind, policy makers are focusing subsidies on distributed and rooftop solar, and offshore wind. In 2019, distributed solar accounted for over 30% of new solar additions. The total subsidy budget for new PV power projects in 2020 is \$0.22 billion, of which \$72.5 million is attributed to household PV.

Total projected distributed energy in China (2019-2025)



Source: GEIDCO

System Value impacts



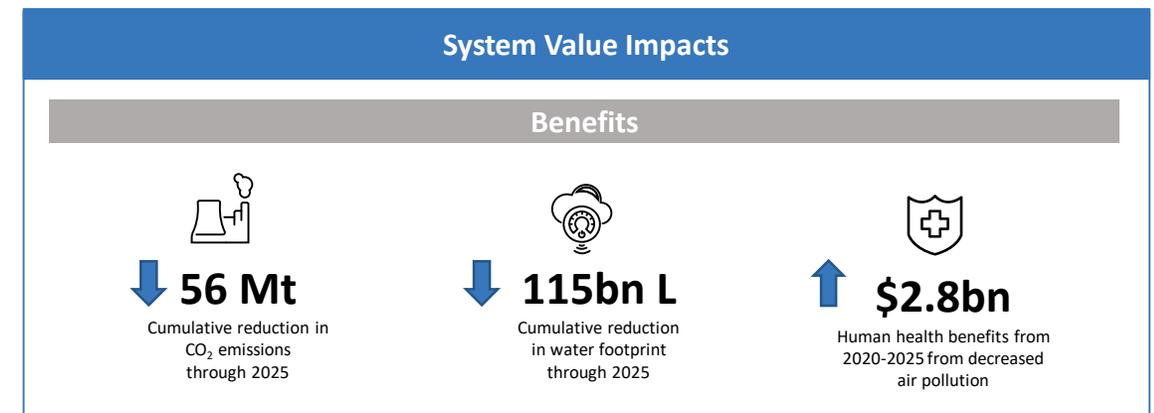
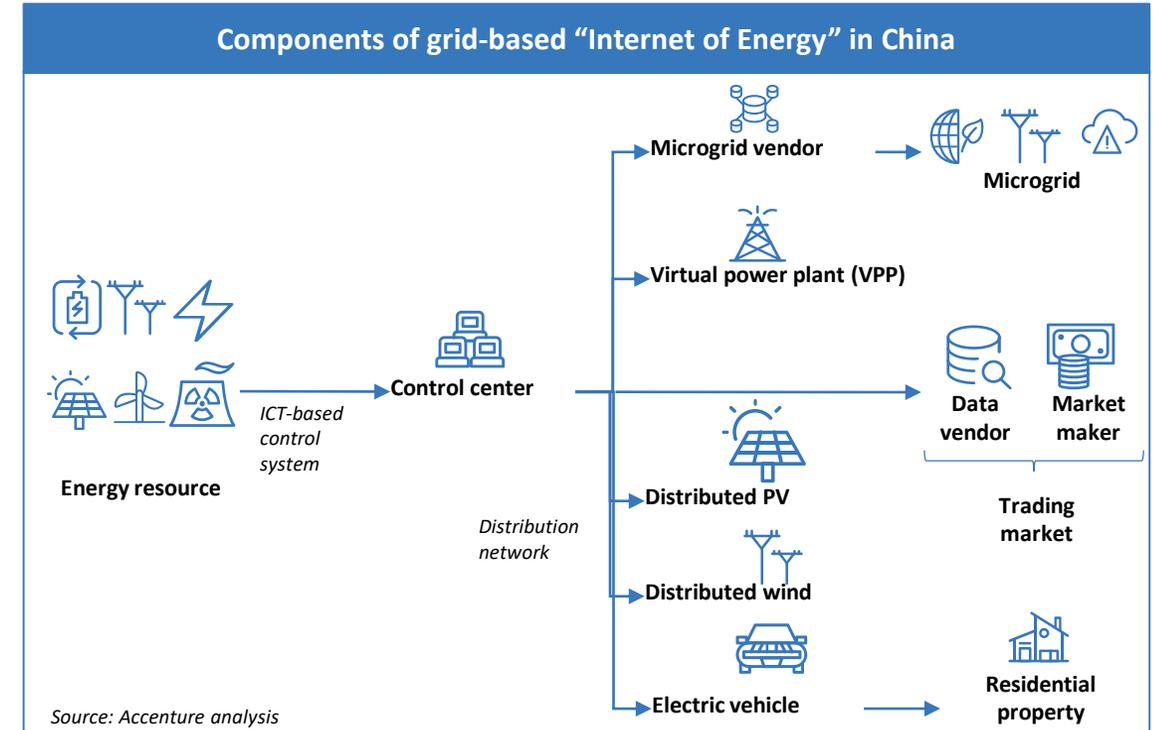
Internet of Energy

Overview

- Energy technology and digital innovation are changing the traditional value chain of energy, leading to the construction of a new digital energy ecosystem in China (“the Internet of Energy”).
- The power loss rate is an important technical and economic index for power grid enterprises. Strengthening power loss management can reduce cost, increase efficiency, improve lean management, effectively detect hidden security risks, optimize the distribution network, and provide users with safer, more reliable power supply services.

Technology innovations/application scenarios

- **Microgrid operation:** In the future, new energy microgrid systems can participate in power transactions. Industrial parks, economic development zones, power generation companies and independent power sales companies could provide a variety of services, which include generating power, carrying out related power distribution and sales, and providing cleaner and cheaper power supply services to end-users on the network. Microgrid revenues could be realized through the purchase and sale model of “peer to peer trading”.
- **EV charging stations:** The core value of charging stations will gradually migrate from hardware manufacturing to charging station operations. In the end, charging stations can play the role of customer ports and traffic portals in the Internet of Energy architecture.
- **Demand-side response and energy efficiency services:** Demand can be divided into end user side demand and power selling side demand. User-side requirements are focused on achieving smart electricity use, including improving production and management efficiency, as well as energy-saving services. The demand on the electricity sales side comes from relying on electricity consumption data (e.g. from smart meters) to provide accurate electricity demand forecasts to achieve real-time matching of supply and demand. The user-side energy-saving and O&M market size exceeds \$14.5 billion currently and is expected to escalate to ~\$150 billion in 2050.
- **Virtual power plant (VPP):** VPPs are primarily composed of multiple distributed power generation systems, energy storage equipment, and communications system. Deployment of VPPs allows for better grid operation and dispatch by integrating various types of distributed energy sources, controllable loads and energy storage devices into a virtual controllable aggregate ‘power plant’ and distributed power management system.



Efficiency Investment

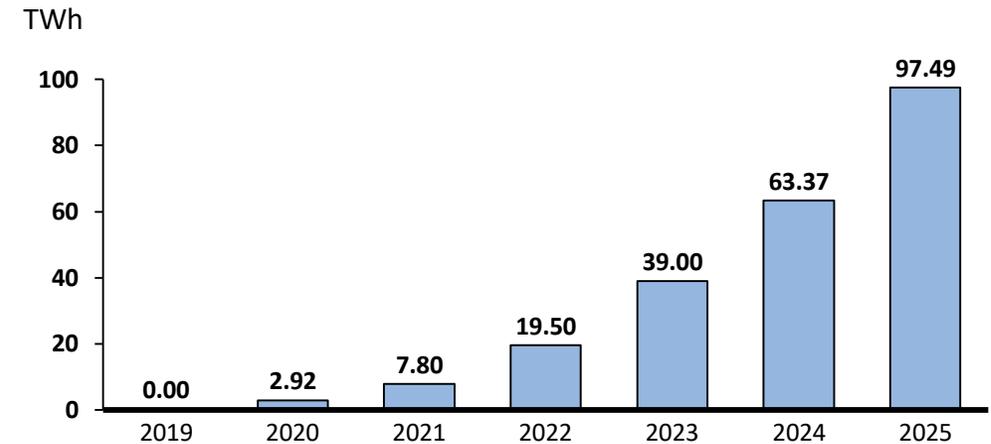
Overview

- According to the IEA, China has been one of the driving forces within the E4 program,¹ responsible for 80% of the efficiency gains between 2000 to 2017 across Brazil, China, India, Indonesia, Mexico and South Africa.
- Within China itself, China's energy consumption per unit of GDP has been falling, mainly through accelerated industrial adoption of energy efficiency initiatives and reduced consumption-side energy intensity.
- The Chinese government set a goal to cut energy intensity by 15% from 2015-2020 and invest \$270 billion in energy efficiency. After three successful years, in 2019, China fell just short by only 3%. The NDRC noted the rapid growth of steel, building materials, non-ferrous metals, chemicals and the service sector as negatively impacting efficiency goals. However, as of May 2020, China remains on schedule to achieve the upcoming five-year reduction target.
- According to C40, by 2016 China's building sector accounted for approximately 20% of the country's total primary energy consumption and 25% of GHG emissions. The majority of consumption is from residential, commercial and public buildings in cities in China, which is expected to increase.

Energy efficiency opportunities and challenges

- Energy efficiency initiatives remain challenging in terms of identifying the client base for energy efficiency applications, as well as the complexity of monitoring implemented policies on the consumer side.
- Meanwhile on the supply side, intensive retro-fitting programmes on coal plants are resulting in increased efficiency and a reduction in emissions across SO₂, NO_x and particulate matter (PM) emissions. For example, from 2015-2018, China Huaneng invested a total of \$2.45 billion to renovate 112 GW of installed coal generation capacity (representing nearly 95% of its entire coal fleet) to ultra-low emission status.
- Further inefficiencies can be addressed through sector optimization (e.g. electrification, grid efficiency, building and industry energy efficiency), as well as cross-sector optimization (e.g. optimized energy consumption through design improvements at the intersection of buildings and mobility).

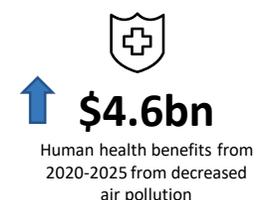
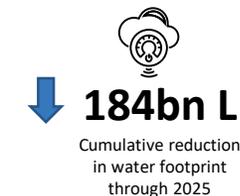
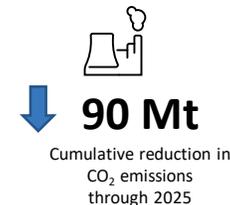
Projected energy savings as a result of efficiency investments



Source: Accenture analysis

System Value impacts

Benefits



Transport Electrification

Background

- China's EV market has maintained steady growth in recent years. China is projected to have 11.38 million EVs by 2025.
- By 2017, mileage of China's high-speed trains had reached 25,000 kilometers, and it is expected to increase to 38,000 kilometers in 2025.
- By 2018, there were about 255,000 electric buses in China, accounting for 75% of the total new-energy buses and 38% of all buses. According to BNEF, the number of electric buses in China is expected to reach more than 600,000 by 2025.
- The road transport sector has a net-zero emissions target set for 2050.
- As of June 2020, China leads globally with 1.32 million charging stations. The NDRC estimates that in 2020, an additional \$1.45 billion will be invested to further expand China's charging infrastructure, with 20,000 public charging stations and 40,000 private charging stations to be added to the existing charging network.

Technology innovations and applications

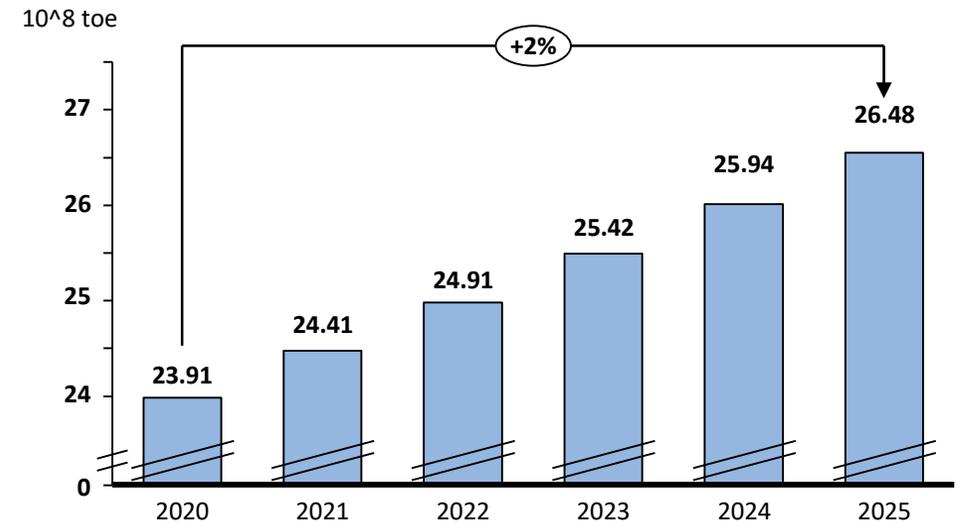
- *Optical storage charging station*: Solar EV chargers are micro-grid applications, with the ability to store energy overnight and charge EVs during peak hours in the day. There are over 36 solar EV charging stations currently in operation.
- *Vehicle-to-grid (V2G)*: It is estimated that by 2030, the number of EVs in China will reach 80 million. When each vehicle is equipped with a battery of 60 kWh, 80 million EVs can provide an energy storage capacity of approximately 4.8 billion kWh. Given an EV is parked on average 96% of the day, this creates significant potential for distributed energy storage. At scale, millions of EVs can provide megawatts of power, hours of discharge time and a response time of minutes or seconds.

Policy and enforcement

- *Electrification of taxis and ride-hailers (PHVs¹)*: In 2019, multiple large cities in China including Beijing, Shenzhen, Chengdu and Guangzhou issued plans to completely replace traditional fuel taxis with new energy taxis. Guangzhou plans to switch all traditional fuel taxis to electric taxis by the end of 2022. Since 2017, Shenzhen, Foshan, Kunming and many other cities have updated their online ride-hailing car registration requirements, specifying that new vehicle registrations must be electric.

Note: 1) Private Hire Vehicles used by ride-hailers, 2) Quantification focused on electric vehicle uptake through 2025
Sources: IDC, NDRC, Qianzhan, Wind, WRI, World Resources Institute, CBEA, Accenture analysis

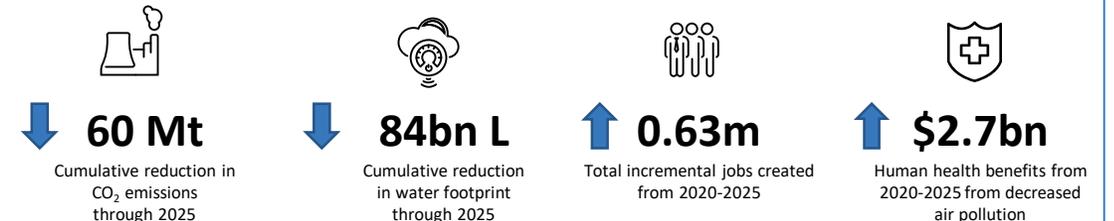
End-use transport energy consumption of China



Source: Energy Outlook 2050 (CNPC ETRI 2019)

System Value impacts of EV growth through 2025²

Benefits



Industrial Electrification

Background

- According to the China Electricity Council, China is progressing on sector electrification and is closing the current electrification gap compared to many European countries (e.g. Germany, Norway, Spain) that are electrifying sectors such as light industry, heat and transport.
- To keep global warming below 2°C, the electrification rate of the end-use sector would need to rise from 24% in 2017 to 53% by 2050 according to China's 2018 Renewable Energy Outlook. Specifically, electrification of the industrial sector would need to rise from 19% in 2010 to 39% by 2050. Currently there is a target to electrify an additional 3% of industrial energy demand by 2025.

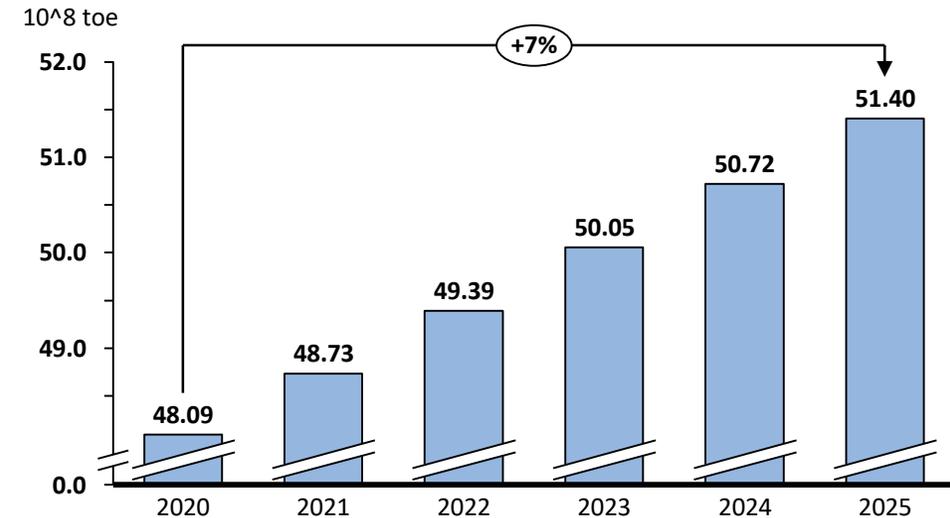
Meeting growing industrial energy demand

- Industrial sector electrification can be led by the transformation of industrial manufacturing, which features high levels of electrification generally.
- To meet expected growth of industrial energy consumption, the implementation of additional zero-carbon sources is needed. The Energy Research Institute of China Huaneng Group notes some possible ways to achieve zero-carbon across sources:
 - *Wind power:* Large onshore wind power bases in the north-east, north and north-west and large offshore wind power bases in the southeast coast
 - *Solar power:* Utility-scale solar in high resource geographies such as Xinjiang, Tibet, Qinghai, Gansu and Inner Mongolia
 - *Hydropower:* Bases on the Jinsha River, Dadu River and Yalong River
 - *Nuclear power:* Speeding up the launch of third-generation nuclear projects

Beyond electrification

- Over the past 15 years, a number of pre-and post-combustion CO₂ capture facilities have been commissioned in China with varying success indicators, from volume of CO₂ stored to cost per tonne captured.
- A sustainable business model is still required for large-scale deployment of these technologies. To address this challenge, China's Ministry of Science and Technology has formed the China CCUS Technology Innovation Alliance, which has 36 members currently, including 16 companies (e.g. Huaneng, Sinopec), 14 universities and six research institutes.

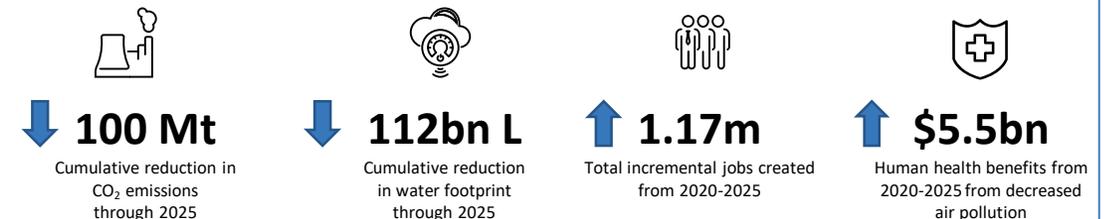
End-use industrial energy consumption of China



Source: Energy Outlook 2050 (CNPC ETRI 2019)

System Value impacts

Benefits



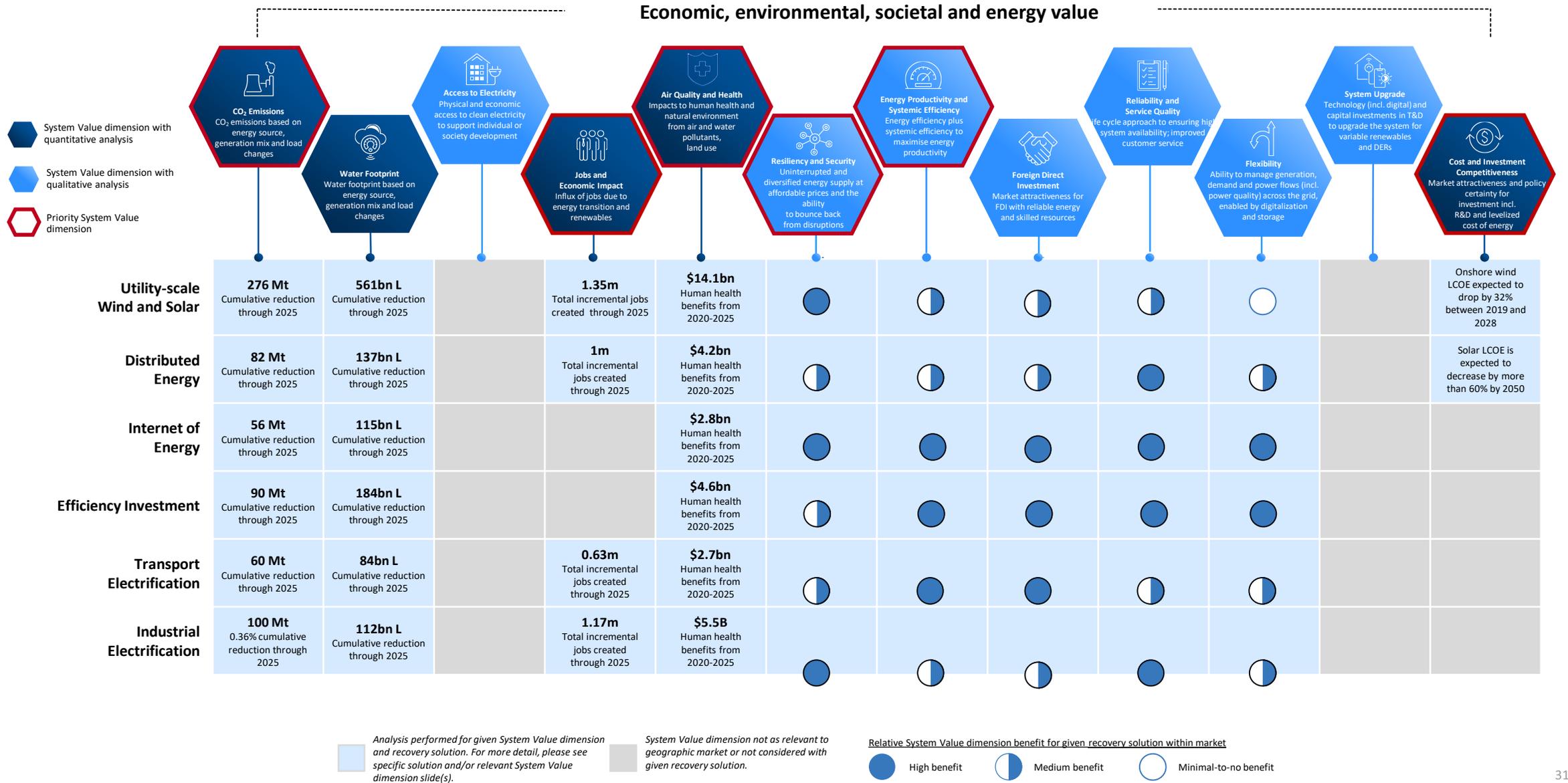
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System Value of clean energy transition

System Value benefits are seen across all recovery solutions for China



System Value dimension: CO₂ emissions

The implementation of identified recovery solutions can help China flatten and begin to decrease CO₂ emissions.

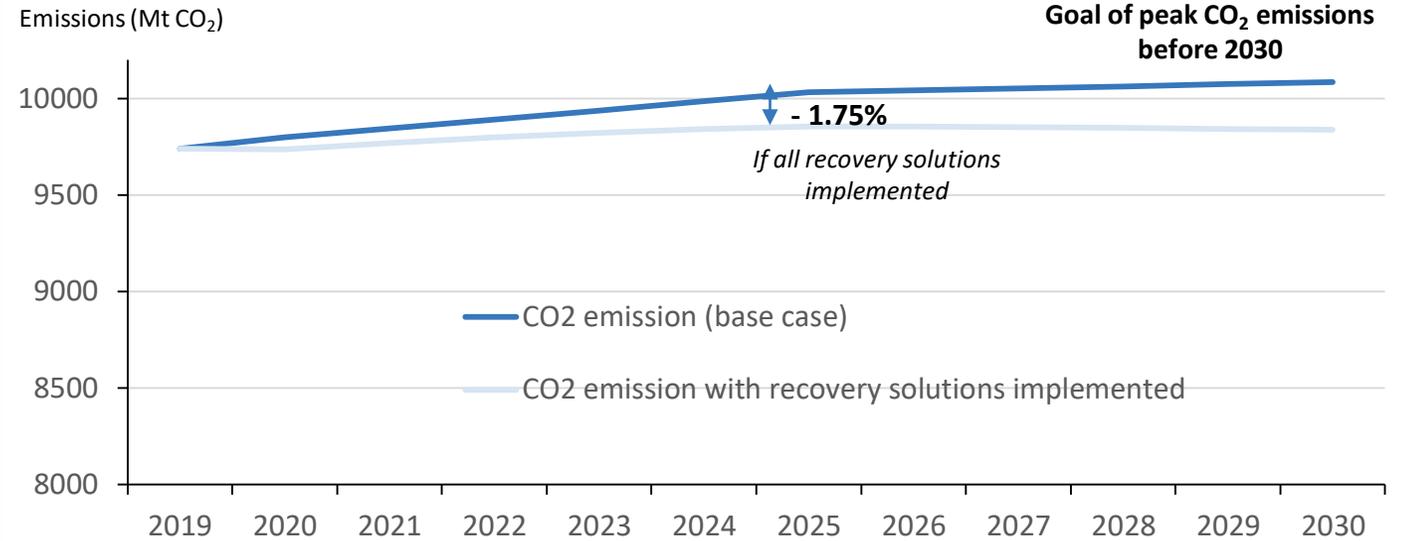
Background

- China became a major global emitter of greenhouse gases through its rapid economic development. In terms of per capita emissions, China is equivalent to developed economies in Europe, although only 45% the amount of per capita US emissions. However, China's absolute scale makes it the world's largest emitter of greenhouse gases, accounting for 28% of global emissions.
- China's total carbon emissions in 2019 are 12,000 Mt, of which over 9,700 Mt (81%) are energy-related.
- The industrial sector accounts for more over 70% of total carbon emissions, highlighting the importance of decarbonisation for the industrial sector.
- Carbon emissions are expected to peak by 2030 in line with recently announced government targets.

Impact of recovery solutions

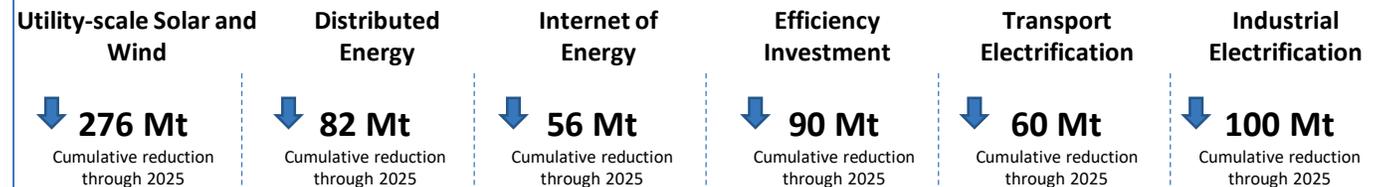
- The implementation of all recovery solutions would have the potential to reduce CO₂ emissions by approximately 665 Mt cumulatively from 2020 to 2025.

China energy-related CO₂ emissions trend from 2019 to 2030E



Base case emissions from Energy Outlook 2050 (CNPC ETRI 2019)

Recovery solution impact on System Value dimension



System Value dimension: Jobs impact

China is a global leader in renewable energy employment, with over 4 million direct and indirect jobs in 2019

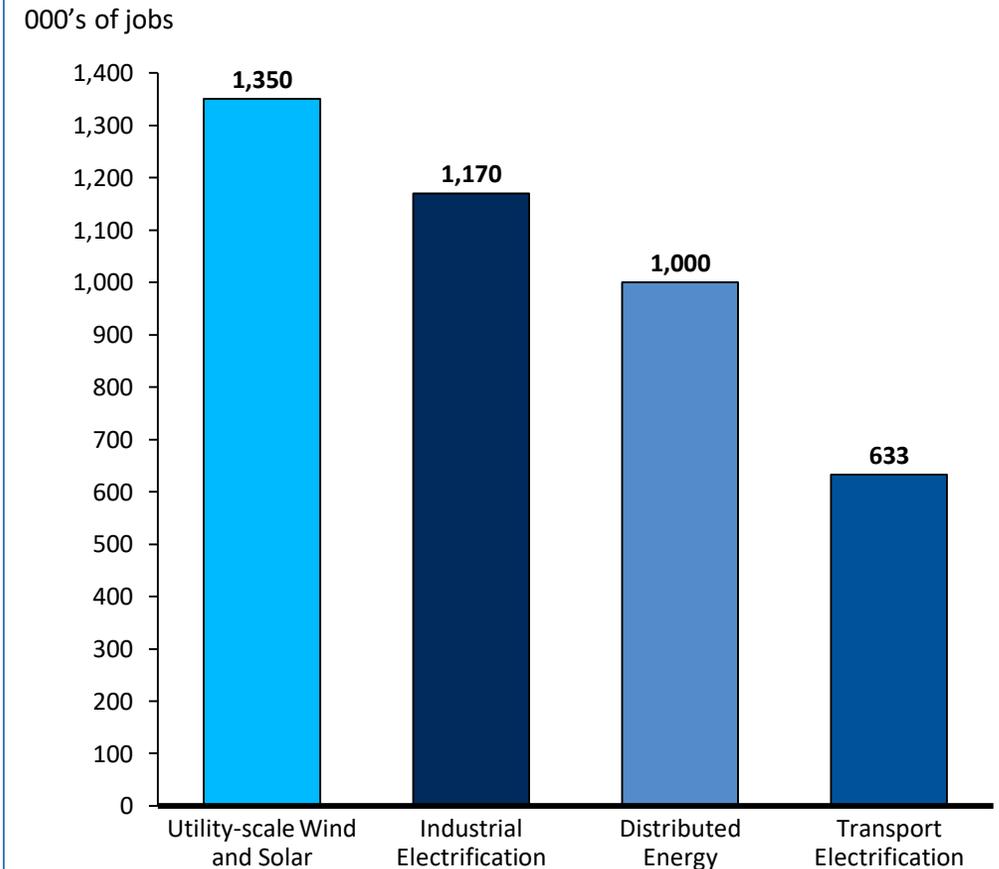
Overview

- China is **the largest provider** of total **renewable energy jobs** worldwide with roughly over 4 million direct and indirect jobs in 2019. According to IRENA, China also leads employment in five different renewable energy sectors: **solar PV, solar heating and cooling, wind, biogas and concentrated solar power (CSP)**.
- Solar PV employment represents 54% of renewable energy jobs in China, nearly 2.2 million direct and indirect jobs in absolute terms.
- Sixteen percent (16%) of renewable energy jobs in China can be attributed to solar heating and cooling, approximately 670,000 employed.
- China's other large renewable energy employment sectors include wind power with 510,000 jobs (12.5%), hydropower with 308,000 jobs (7.6%), and solid biomass with 186,000 jobs (4.6%).

Commitment to job creation

- China has committed to developing renewable energy to displace the use of fossil fuels, particularly through increasing exports of solar PV to emerging markets via the International Investment Alliance for Renewable Energy.
- If recovery solutions are realized, there is potential for an additional **4.16 M** jobs to be created cumulatively from 2020 through 2025.

Impact on jobs across recovery solutions through 2025



Source: Accenture analysis

System Value dimension: Air quality and health

Decreasing coal consumption can improve China's air quality, with the country's air pollution levels ranking among the highest in the world as few enforcement standards are currently in place.

China overview

- Air pollution has become a major issue in China and poses a threat to Chinese public health. In 2016, only 84 out of 338 prefecture-level or higher cities attained the national standard for air quality.
- In the last few years, China has made significant progress in air pollution management. For example, average PM2.5 concentrations fell by 33% from 2013 to 2017 in 74 cities, and overall pollution levels in China fell by a further 10% between 2017 and 2018. In August 2019, Beijing experienced the lowest PM2.5 on record with Beijing on track to drop out of the Top 200 most polluted cities.

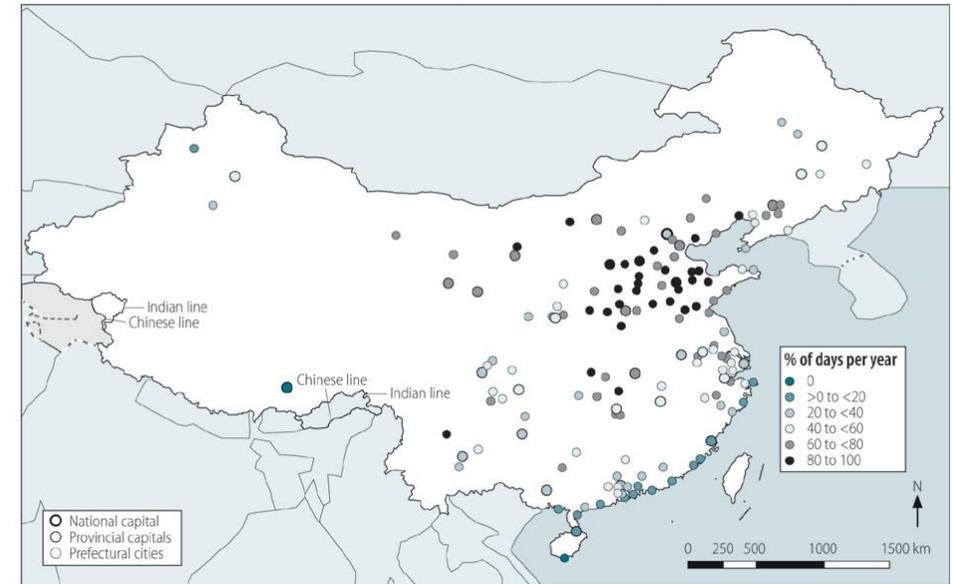
Key actions to improve air quality

- Switch away from coal (according to the 13th Five-Year Energy Plan, the proportion of coal will drop from 58% in 2020 to around 50% by 2030, with consumption of more than 4.2 billion tonnes)
- Conduct afforestation measures
- Become a global leader in the transition to EVs

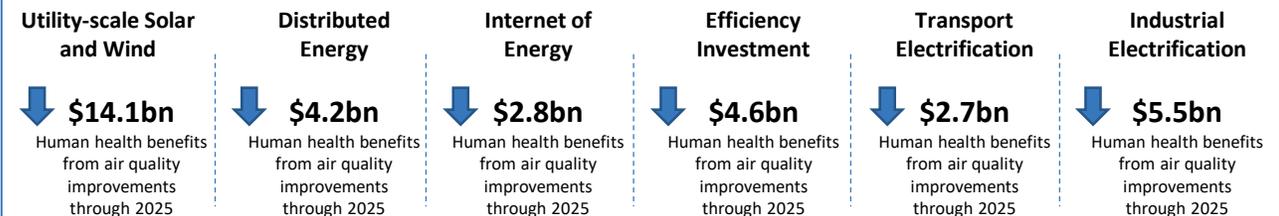
Policy and enforcement

- Investment levels in air pollution reduction are being increased by the Chinese government to combat pollution. For example, in 2013, China's Academy for Environmental Planning pledged \$277 billion to combat urban air pollution.
- In the first batch of 74 cities that implemented the 2012 Environmental Air Quality Standards, the average concentration of PM2.5 and SO₂ dropped by 42% and 68% respectively between 2013 and 2018.

Locations of cities with high mean daily air concentrations of PM2.5 and SO₂



Recovery solution impact on System Value dimension



System Value dimension: Resiliency and security

The clean energy transition enables greater resiliency and security for China through more domestic energy and secure, digital operations, better insulating China's system from foreign shocks and natural disasters.

Resiliency and security benefits by recovery solution	
Utility-scale Wind and Solar	 <ul style="list-style-type: none"> Greater security through domestic renewable electricity from utility-scale wind and solar, with less reliance on fuel imports.
Distributed Energy	 <ul style="list-style-type: none"> The establishment of distributed energy micro-grids, especially in disaster-prone areas, can better provide emergency energy supply after disasters and improve overall disaster resistance ability.
Internet of Energy	 <ul style="list-style-type: none"> The Internet of Energy provides strong security awareness and protection, accident risk prevention and an ability to self-heal.
Efficiency Investment	 <ul style="list-style-type: none"> The promotion of smart grid will bring increased system resiliency and protection from system shocks.
Transport Electrification	 <ul style="list-style-type: none"> EV battery technology applications can be leveraged as a local power source for longer-term outages, for example during natural disasters.
Industrial Electrification	 <ul style="list-style-type: none"> Through clean electrification of the industrial sector and the replacement of fossil energy, China will reduce its dependence on other primary energy sources, especially oil and natural gas which it must import from other countries.

System Value dimension: Energy productivity and systemic efficiency

Efficiency improvements to remove waste and optimize the energy system across the value chain can be achieved through identified recovery solutions.

Energy productivity and systemic efficiency benefits by recovery solution	
Utility-scale Wind and Solar	 <ul style="list-style-type: none"> Renewables deployment can be prioritized towards high availability geographies that maximize capacity factors, getting more for less.
Distributed Energy	 <ul style="list-style-type: none"> As a comprehensive energy utilization system positioned close to the end user, distributed energy has the potential to lower T&D losses due to more local generation.
Internet of Energy	 <ul style="list-style-type: none"> China's Internet of Energy will help balance supply and demand and greatly improve energy efficiency. Internet of Energy can also improve power generation operations, with the world's most efficient gas-driven CCHP system increasing its efficiency to 94%, double that of centralized power generation.
Efficiency Investment	 <ul style="list-style-type: none"> End consumer efficiency improvements can be achieved across sectors through smart appliances, greater building efficiency, and energy conservation, achieving same work or economic output for less consumption.
Transport Electrification	 <ul style="list-style-type: none"> EVs are more efficient than their fossil fuel counterparts, converting over 77% of the electrical energy to power at the wheels, whereas gasoline vehicles only convert 12%–30% of the energy stored in gasoline. EVs can enhance the integration of solar and wind generation by aligning EV charging with resource availability.
Industrial Electrification	 <ul style="list-style-type: none"> "A guide to demand side management in the industrial sector" by the Ministry of Industry and Information Technology of China notes that promoting electrification in the industrial field is conducive to optimizing the consumption utilization efficiency of industrial power.



System Value dimension: Cost and investment competitiveness

Outlook for variable renewable LCOE is promising as deployments continue to see cost reductions, with solar LCOE expected to decrease by more than 60% by 2050.

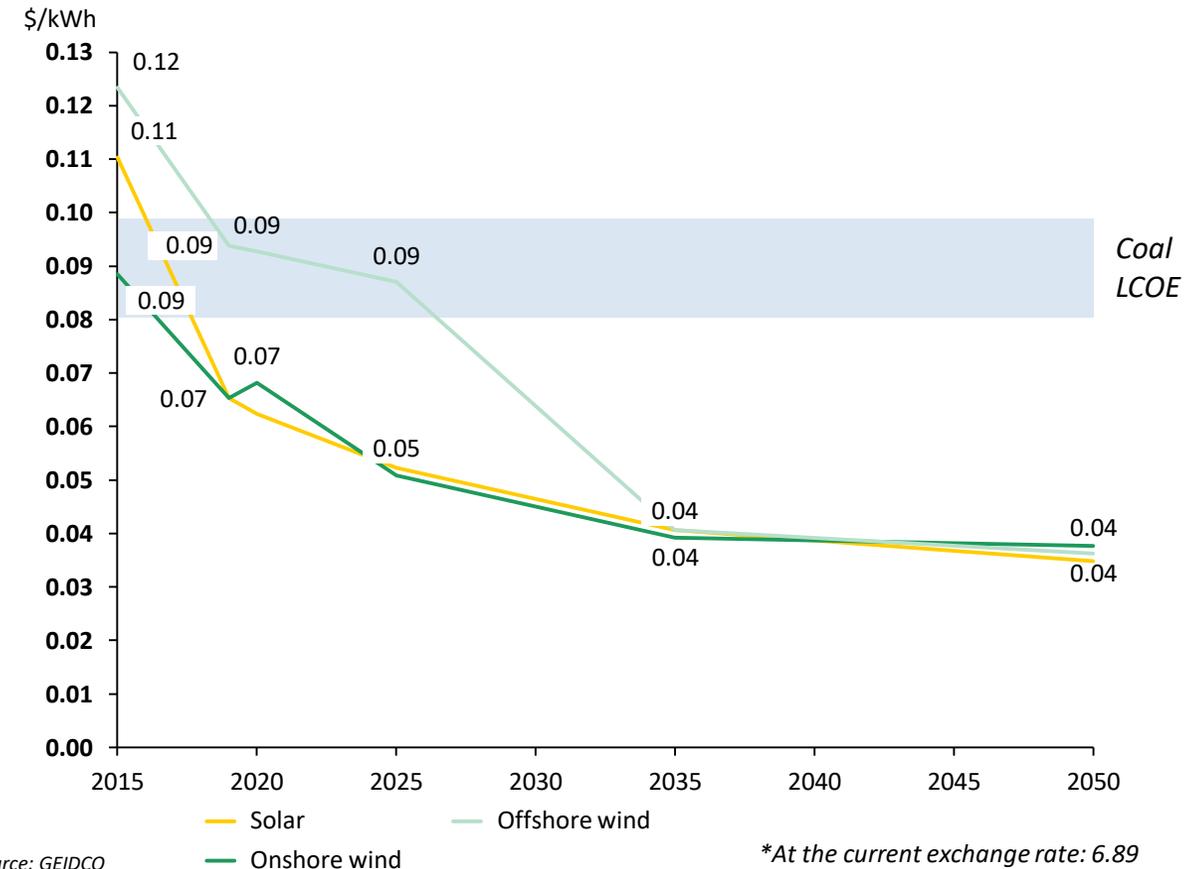
Overview

- As China moves toward a subsidy-free era for wind and solar projects beginning in 2021, the economics of renewable power have come into the spotlight. LCOE for solar and wind power have been falling significantly in recent years as seen in the chart on the right.

Levelized Cost of Energy (LCOE)

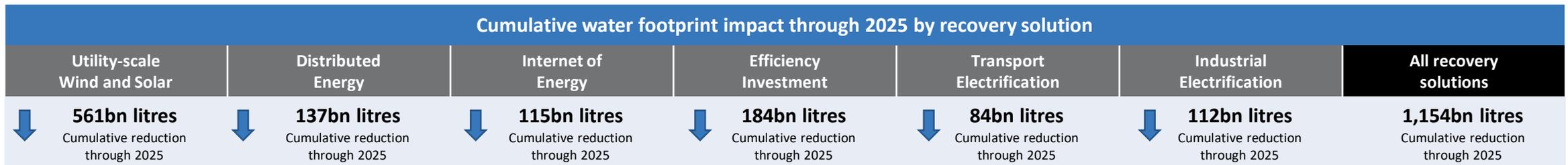
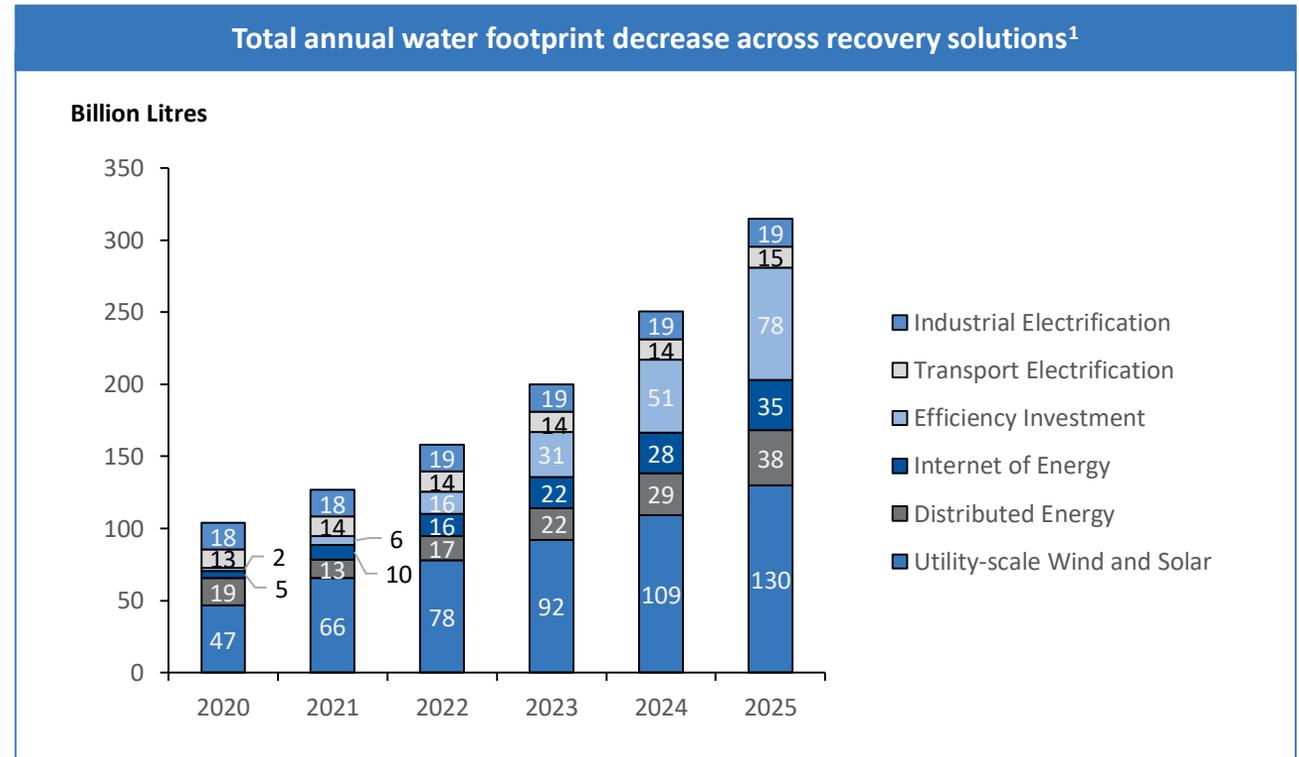
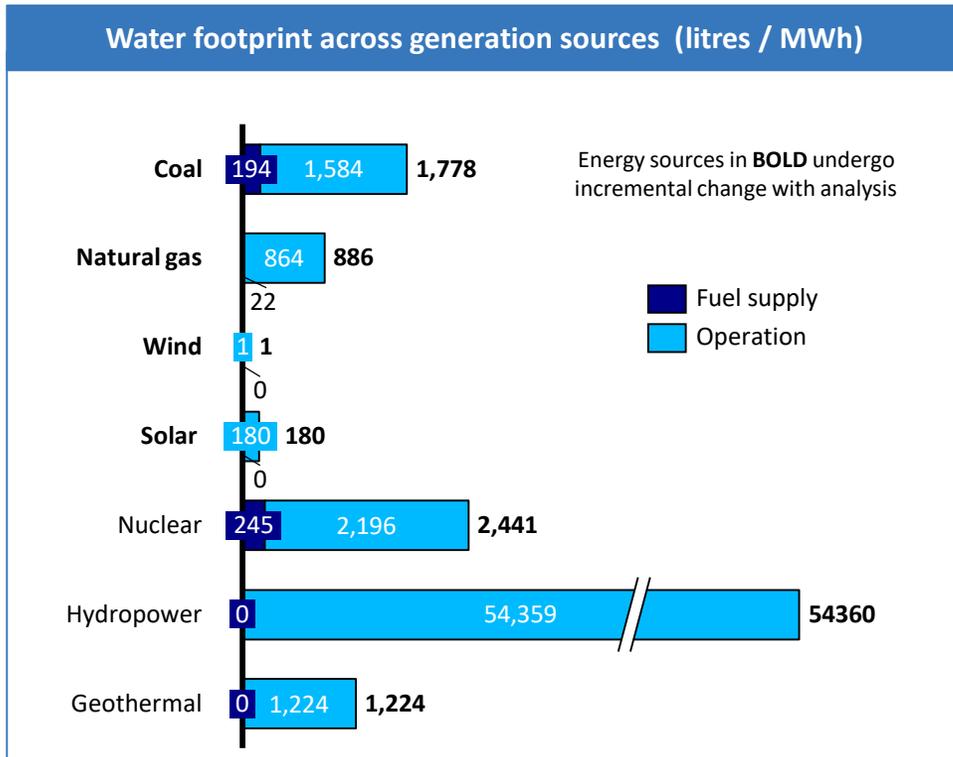
- Renewable energy is becoming highly competitive with fossil fuels:
 - Solar LCOE is expected to decrease by more than 60% by 2050.
 - Onshore wind LCOE is expected to drop by 32% in China between 2019 and 2028.
 - The average LCOE for solar and wind power is already lower than gas-fired power in China and is expected to drop below coal LCOE by 2035.
- Lower LCOE for variable renewables has resulted in an increase in wind and solar projects, greater international competition bringing a large number of experienced developers into emerging markets, and technological improvements.

Average LCOE projections in China



System Value dimension: Net water footprint

While China does not experience significant water scarcity at present, fuel supply and electricity production should be evaluated in terms of risks of water shortage, particularly on a regional basis.



System Value dimension: Foreign direct investment

The clean energy transition can spur greater foreign direct investment into the energy sector.

Foreign direct investment benefits by recovery solution	
Utility-scale Wind and Solar	 <ul style="list-style-type: none"> The China National Development and Reform Commission and the China National Energy Administration have been promoting plans to make wind and photovoltaic power more affordable without subsidies. More foreign investment is expected as the costs of wind and solar PV come down.
Distributed Energy	 <ul style="list-style-type: none"> Over the past decade, China's distributed energy market has seen a 20% increase in investment, of which distributed PV is the key growth market, with an investment of \$19 billion in 2017. By 2030, the investment scale of China's distributed energy market will reach a breakthrough of hundreds of billions, with a CAGR of nearly 28%, of which distributed photovoltaic accounting for nearly 40%.
Internet of Energy	 <ul style="list-style-type: none"> The Internet of Energy has attracted a large number of non-traditional power enterprises, stimulating enthusiasm of innovation and cross-border integration, and is expected to further attract VC and PE to invest in this field.
Efficiency Investment	 <ul style="list-style-type: none"> In recent years, large-scale upgrading of urban power grids has been carried out, resulting in a huge increase in capital demand, which is expected to cost over 700 billion RMB to implement from 2011 to 2021. The Chinese government is also expanding financing channels and using commercial mechanisms to attract non-governmental capital to participate.
Transport Electrification	 <ul style="list-style-type: none"> Since 2014, with the introduction of policies to support the development of EVs, China's EV market has seen rapid growth, with China now the world's largest new energy automobile market. Tesla has invested more than 1.1 billion RMB to buy land in Shanghai to build its first overseas car factory.
Industrial Electrification	 <ul style="list-style-type: none"> Electrification is a stable booster of energy investment. With the advancement of China's industrialization and urbanization, the proportion of electric power consumption in the terminal energy is gradually increasing, creating investment opportunity.



System Value dimension: Reliability and service quality

Ensuring grid reliability for a majority variable renewable system will be critical for China in the coming decade, with investments in batteries and hydrogen storage on the horizon alongside the creation of next-generation network and power markets.

Reliability and service quality benefits by recovery solution		
Utility-scale Wind and Solar		<ul style="list-style-type: none"> Renewable energy plus storage systems can improve the overall power supply reliability and load rate, but most projects are still in demonstration phases. Energy storage projects directly combined with utility-scale solar are mainly concentrated in areas with abundant solar resource and concentrated large-scale photovoltaic power stations, such as Qinghai.
Distributed Energy		<ul style="list-style-type: none"> Distributed energy can ensure the supply of local energy in rural areas, effectively improving the reliability of energy supply.
Internet of Energy		<ul style="list-style-type: none"> Through data collection and intelligent control, wind and solar farms can become more efficient and reliable. For example, wind farm operators will be able to understand possible faults of the units according to the collected data and can receive preventive O&M plans to improve the safe and stable operation of units.
Efficiency Investment		<ul style="list-style-type: none"> Smart grid is a power grid automation system, which can improve power supply reliability.
Transport Electrification		<ul style="list-style-type: none"> China has been carrying out research and pilot programmes on V2G and encouraging electric vehicles to participate in grid load frequency control, which can improve the reliability of grid operations and provide clean energy services for transportation.
Industrial Electrification		<ul style="list-style-type: none"> Industrial electrification with digital management platform could help provide value-added services.



System Value dimension: Flexibility

System flexibility will become more vital as the generation share of renewables increases; however, China faces short and medium-term challenges in balancing its ambitious renewables targets with the flexibility requirements of its current power system.

Overview of system flexibility in China's electricity sector

Overview

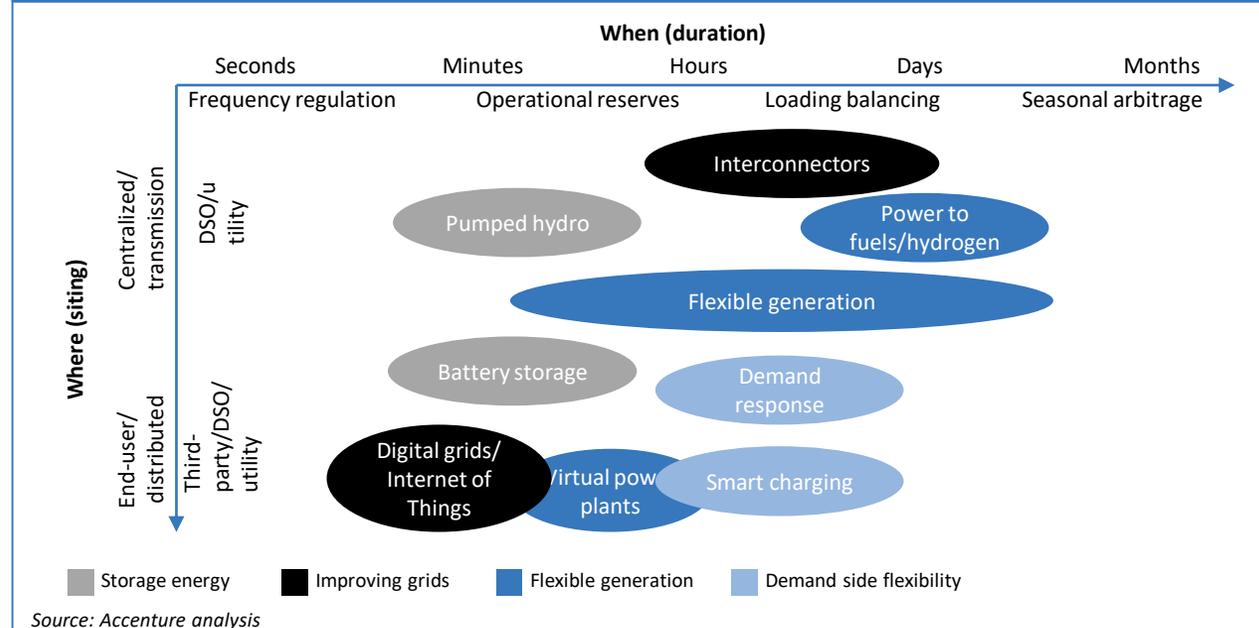
- The participation of renewable energy sources and storage in ancillary markets (such as primary frequency control and AGC) is commonly practiced in China to increase grid flexibility
- "Generation-Grid-Load-Storage" coordinated development is also facilitated by the National Energy Agency of China through a recent report in August 2020 to enhance flexibility of the power system. It is expected to be promoted in China during the 14th Five-Year plan. This could result in a 2.5 TWh annual increase in wind and solar penetration.

Actions to boost flexibility and investment

- *Power-power coordination:* VRE intermittence and fluctuation issues linked to climate change can be managed through coordinating flexible thermal generation and renewables.
- *Power-grid coordination:* The adoption of new dispatch technologies can resolve issues related to injecting large-scale renewables and DER into the grid.
- *Grid-load interaction:* The transformation of load to the grid's dispatchable resources, as flexible load (demand response).
- *Grid-storage interaction:* Storage energy can be charged in the form of load in valley time and generate power at peak hours.
- *Power-load interaction:* Generation and demand side act as dispatchable resources to aid power balancing control.

Sources: Accenture analysis

Overview of different power system flexibility resources



Recovery solution impact on System Value dimension

